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THE TOWER OF THE NEW CITY HALL AT PHILADELPHIA, PA.

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WITH DISCUSSION.

Volumes innumerable have been written treating of the theory, design and construction of plane trusses, trusses whose members have their axes lying in one and the same plane; and it has long been the practice to construct domes, conical roofs, etc., supported by a number of such trusses occupying planes radial to the vertical axis of the structure. J. W. Schwedler conceived the idea of designing the wrought-iron "mantle construction," which bears his name, in which the stresses occur and are taken up in the mantle of the structure, leaving all the interior space unoccupied by trusses.

The literature of trusses having any position in space (German, *räumliches Fachwerk*) is as yet very scanty, and a general and exhaustive theory of such trusses has yet to be written. Hence, and inasmuch as the wrought-iron tower framework surmounting the masonry tower of the new City Hall at Philadelphia is a construction

of this kind, the writer believes that no apology is necessary for presenting the following account to this Society.

General Description of the Work.—Up to a height of 337 ft. $4\frac{1}{2}$ ins. from the street level the tower of the City Hall is of brick, faced with marble, and this portion is now practically completed. In order to avoid excessive pressure upon the foundations, the commission in charge of the erection of the building decided to construct the remaining portion (about 173 ft. in height) of metal, and the contract for this, complete, including statuary, was awarded to the Tacony Iron and Metal Company, at Tacony, Philadelphia. The architectural design of the tower, shown on Plate XXXI, furnished the sole basis for the engineering design, and was the work of the late Mr. John McArthur, the architect of the building.

The tower was placed in charge of the writer by the Tacony Iron and Metal Company, who designed the engineering work in general and in detail.

The framework of the entire metallic structure (Plate XXXII), resting upon granite blocks, consists essentially of an octagonal prism surmounted by an octagonal pyramid of the same diameter at base as that of the prism. Throughout the entire height of the prism and pyramid their horizontal sections form regular octagons. This wrought-iron framework may be divided into a primary and a secondary construction. The former constitutes the true skeleton of the structure, while the latter, immediately surrounding the primary construction, forms the direct support of the shell, and transmits to the primary construction the wind pressure upon it, and, in the case of the pyramid, its weight also. In the case of the prismatic portion, the weight of the shell is carried by the secondary construction directly to the masonry of the tower. The octagon of the prism passing through the centers of the eight columns of the primary construction has an inside diameter of 49 ft. $1\frac{1}{8}$ ins., and an outside diameter of 53 ft. $1\frac{21}{32}$ ins.; the octagon at the top of the pyramid has an inside diameter of 4 ft. 6 ins., and an outside diameter of 4 ft. $10\frac{1}{2}$ ins. The height from the top of the granite to the center of the connection between the prism and the pyramid measures 67 ft. $4\frac{1}{8}$ ins., and the height from the latter point to the top of the tower-cap is 104 ft. $3\frac{7}{8}$ ins. The tower-cap will receive the colossal bronze statue of William Penn, which is 37 ft. high, and as the granite level is 1 ft. 7 ins. above the level of the marble, we have

a total height from the ground to the top of the statue of William Penn of 547 ft. $7\frac{1}{2}$ ins. Other main dimensions can readily be taken from the general design.

The primary construction is divided into ten stories, three for the prism, and seven for the pyramid; and it consists of the eight rafters forming the corners of the pyramid, and of the eight columns forming those of the prism, together with the octagonal braced rings and the diagonals. A panel of this "truss in space" is comprised between two rafter sections of the pyramid (or two column sections of the prism), and two ring sections, one above the other. Each panel is crossed by two diagonals, as shown. These diagonals are designed for tension, and those in the three top stories for compression also.

The eight columns of the prism rest upon four wrought-iron box girders, marked *G* (Plate XXXII). These girders rest upon cast-iron wall plates 3 ft. wide, 11 ft. long and $2\frac{1}{2}$ ns. thick. These wall plates are placed under the centers of the box girders, and, inasmuch as the latter are 24 ft. 4 ins. long from out to out, there is at each end a projecting arm, or cantilever, 6 ft. 8 ins. long. The columns of the prism are supported by these projecting arms 4 ft. 8 ins. from the ends of the wall plates. This arrangement is necessitated by the fact that only those portions of the masonry of the tower under the wall plates are so constructed as to bear the weight imposed.

Each of the wind bracings consists of two sets of horizontal tension members acting in connection with the compression members which form the octagonal ring at the top of each story; each set consists of four members forming a square. These members are square bars, except in the two uppermost stories, where they are of angle iron. Since the feet of the columns in the prism are anchored to the box girders, wind bracing is not required at that point. The octagonal ring has, however, been retained. Such horizontal structures permit only such deformations of the tower framework as are due to the elasticity of the material. The selection of this form of bracing was dictated by the necessity for a spiral staircase within the tower, reaching from the top of the stone tower up to the balcony. It is true that the bracings might have been placed on the outside of the primary construction, but practical considerations rendered such an arrangement undesirable.

The secondary construction of the prism consists essentially of

four skeleton columns, 56 ft. 9 ins. high, marked *P*, and four arches, each of 36 ft. 3 ins. span, marked *A*, together with three octagonal rings, and 76 vertical posts inserted between those rings.

The secondary construction of the pyramid consists essentially of octagonal rings, which support the jack rafters.

There are, in all, three floors and one balcony to be carried by the tower framework. The first floor is at the top of the prism; the second, about in the middle of the sixth story, and the third, at the top of the seventh story. A door in the shell of the tower leads from the third floor to the balcony.

It was originally intended to build the first floor of concrete laid upon corrugated iron arches placed between I beams ; but, in order to reduce the weight, it was decided to use steel plates and rubber. The cantilevers supporting the present floor were designed and built to carry a concrete floor. They are pin-connected trusses, and spring from the columns of the prism, to which they are attached by pins. The top and bottom chords of these cantilevers are made each of two channels, connected by plates ; the posts are composed of four angles and one web, and the diagonals are square bars. A stiff ring, made up of plates and angles, unites the ends of the eight trusses, leaving in the center a vacant space of about 12 ft. in diameter. The thrust of the bottom chords of the cantilevers, which would produce a bending moment on the columns, is taken up by eight tie rods running around the prism. By means of pins these tie rods are connected with bent plates attached to the outer sides of the columns, and, to prevent buckling of the angles of the columns, two stiffeners are riveted on each side of the latter. Although the feet of the pyramid rafters are connected with each other by struts, to which the diagonals are attached, tie rods, with such details as just given, intended to take the outward thrust caused by the pyramid, are placed around the top of the prism. The feet of the rafters of the pyramid are centrally connected with the heads of the columns of the prism by means of pins $4\frac{1}{16}$ ins. in finished diameter. These pins are in the same horizontal plane with the tie rods just referred to. The wind bracing at the top of the prism is placed as near as practicable to the top chords of the cantilevers. A horizontal structure of the same description has also been inserted, as near as possible to the level of the second floor, to avoid the bending moment exerted by the upper chord of the can-

tilevers of this floor upon the rafters, and tending to bend them inward. From this floor a view may be had through the lunette windows. The supporting parts of the second floor are made of angles and plates. The wind bracing at the top of the seventh story is also placed as close as practicable to the level of the floor. The rafters of the seventh story are built as trusses. They carry the third floor and the balcony, and during erection a false work from 75 to 80 ft. high, to be used in the mounting of the statue of William Penn.

The several floors of the tower are composed of I beams bolted directly to the brackets which support them. Steel plates, $\frac{1}{4}$ in. thick, are secured to the tops of the I beams by means of bolts having countersunk heads, and a layer of rubber about $\frac{1}{2}$ in. thick will form the floor surface. The only exception to this is the floor of the balcony, which will be finished with a layer of asphalt. This latter floor is several inches lower than the adjacent third floor in order to prevent rain water from entering the tower.

Brackets attached to the rafters of the pyramid, and consisting of two horizontal and two inclined angles, carry at their extremities struts, which in turn carry the jack rafters. To the latter the shell is fastened by light cast-iron brackets, as already observed. At the center of each jack rafter are two lattice bars, one running from the top angle to the rear of the strut, and the other from the bottom angle to the same point. They are designed to prevent buckling of the angles in front of the strut.

It will be seen from the plan, Plate XXXII, that on each of four sides of the tower—each two sides being opposite—and just outside of the prism, are two pairs of cast-iron columns, indicated by dotted lines, and behind each pair of columns stands a pair of pilasters, also indicated by dotted lines. The columns are 2 ft. 8 ins. in diameter at bottom, tapering to 2 ft. 4 ins. at top, and the width of the pilasters is about the same, with a depth of 15 ins. The metal in both columns and pilasters is about 1 in. thick, and their height is 37 ft. Each pair of columns, with the corresponding pair of pilasters, is bolted to the masonry, and the four are united at the top by a heavy cast-iron plate. On these plates rest the feet of wrought-iron arches of 36 ft. 3-in. spans (see Plate XXXII) having a uniform depth of 3 ft. 6 ins. and a width of 3 ft. $5\frac{1}{4}$ ins. The inclined members running from the second panel point at each end to the points of support are

designed to add to the rigidity of the arch. These arches are built of plates and angles. Each end is held down by three 1¼-in. bolts, and free to slide upon the planed surface of the supporting plate. The load on an arch is about equally distributed, so that the overturning moment is inconsiderable. To meet this moment, however, the crown of the arch is anchored by a plate 14½ ins. wide, 5 ft. 6 ins. long, and ½ in. thick, to the foot of a post, standing in the rear, and thus indirectly to the primary construction. Upon granite blocks at the four corners of the tower and just outside of the octagon of the prism stand four wrought-iron skeleton columns, bolted down to the blocks, each by eight 1¼-in. bolts; they are marked *P*, and are 56 ft. 9 ins. high, 5 ft. 6 ins. square, and built of angles and plates. Three octagonal rings, a part of the secondary construction, surround the prism. Each section of these rings is a box strut, 18 ins. square. Between the lowest and intermediate ring and between the latter and the upper ring are inserted 76 wrought-iron vertical posts, each built of four angles, I-shaped, latticed and spaced not more than 4 ft. apart. To these posts the upper part of the shell is fastened by means of bolts and cast-iron brackets. These rings are placed between the primary construction on the inside, and the arches and the skeleton columns on the outside. Those ring sections which pass the rear of the arches are fastened to and carried by them, and consequently the posts and the ring sections, lying all in the same vertical plane, together with the upper parts of the shell of the prism on these sides, are finally carried by the wrought-iron arches which transfer the dead weight through the columns and pilasters to the granite. To the outer faces of the arches are attached triangular brackets carrying the pediments. To the bottom of the arch is attached an ornament representing branches with foliage. This is 26 ft. in length and extends in a vertical plane parallel with the side of the prism and nearly under the center line of the arch. On the crowns of the arches are placed wrought-iron boxes to receive the bronze eagles. The writer carried out the same idea, as far as the distribution of dead weight is concerned, on the remaining four sides with the skeleton columns. On these four sides the vertical posts between the lowest and intermediate rings are omitted as superfluous. As will be seen from the diagrams, the ring sections are carried by brackets on the inner faces of the columns, and the outer faces of the latter carry, partly by wrought-iron and

partly by cast-iron brackets, the larger part of the corners of the shell. The weight of the shell of the prismatic or lower portion of the structure is thus transferred, as already remarked, by the arches and cast-iron columns and pilasters and by the skeleton columns directly to the masonry, independently of the primary construction. Each of the four skeleton columns is to carry a statue 24 ft. in height. These statues have cast-iron ground-plates. They represent respectively an Indian with a dog, a squaw with a child, a Swede with a child, and a Swedish woman with a lamb. On top of the cast-iron columns is a light wrought-iron framework to carry ornaments. Cast-iron brackets for shell attachment are spaced 4 ft. apart as a maximum.

Although, as already explained, the weight of the prism shell is carried to the masonry independently of the primary construction, its wind stresses are carried to that construction by horizontally rigid connections composed of angle-iron brackets and bolts.

The eight columns resting upon the box girders are each bolted down by five $1\frac{3}{8}$-in. round bolts, and, as a further anchorage, two $1\frac{1}{4}$-in. square rods will be used for each column. These square rods have open turn-buckles and run across the tops of the channels and the bottom of the box girders. Each of the four supporting girders is secured to the masonry by two anchor bolts, 3 ins. in diameter and extending through the entire depth of the girders and 50 ft. into the masonry. These bolts are in close neighborhood of cross-plates between the webs of the girders and pass through slotted holes, thus allowing for expansion and contraction under changes of temperature.

The tower-cap is in two pieces, as is also the bronze base-plate for the Penn statue. The splice lines of the tower-cap and base-plate are at right angles to each other. The connection between the statue and the tower is effected by 10 2-in. round steel anchor bolts with the nuts inside the feet, the bronze plate acting as filling piece. The image of Penn and the tree trunk upon which Penn's hand rests are connected by 50 $\frac{3}{4}$-in. bolts, the center of this connection being about 16 ft. from the top of the ground-plate; 36 1-in. bolts attach the tree trunk to the bronze plate, and eight 2-in. round steel eye-bolts with 3-in. turned pins, passing through double brackets, connect the bronze plate with the tower.

All rafters of the pyramid and all columns of the prism have two web plates and four angles latticed, and only in the case of the

bottom columns a cover plate has been added. The tie rods of the wind bracing are pin-connected; the lateral details consist of two plates and four angles. These plates and angles form a diaphragm and protect the columns and rafters from the thrust of the rings. The eight struts, forming one of the octagonal rings of the primary construction, are made of four angles. These struts are box-shaped for the prism and latticed on all four sides; for the pyramid they are I-shaped and latticed, while the two uppermost rings have a solid web. The diagonals are pin-connected to the struts. All tension members have either clevises or single eyes with open turn-buckles. The jack rafters are made of two angles, curved to a radius of 136 ft. 2 ins., and trussed. The main and lateral pins are of steel, turned, and the pin-holes are $\frac{1}{64}$ in. larger in diameter than the pins.

It has been the aim of the writer to design all details centrally, and in case a bending moment is thrown on a member, in addition to the stress due to its position as a member of the structure, such member has been proportioned to resist both.

The tower-shell is of cast iron, except the louvres of the pyramid where steel plates have been used $\frac{1}{8}$ in. thick. This material was selected for the louvres in order to save weight. The thickness of the shell for the prism is from $\frac{5}{16}$ in. to $\frac{3}{8}$ in., and that for the pyramid from $\frac{1}{4}$ in. to $\frac{5}{16}$ in. The lower sections of the eight sides of the pyramid, reaching nearly up to the balcony, form parts of a cylinder with a radius of 137 ft. 6 ins. The four clock dials are placed below the arches and have a diameter of about 22 ft. They will probably be illuminated by electric light.

It is not considered necessary to go into a minute description of the shell, as the general plan shows it in its outlines.

All wrought-iron and cast-iron work for the tower was nearly finished in 1892, and the wrought-iron framework for the prism has already been set in place.

Plating.—In order to avoid the great expense involved in keeping the iron-work painted and free from rust, the tower-shell will be electroplated with copper; but as this metal turns green and becomes unsightly, it is given a finishing coat of aluminum, which harmonizes well in color with the rest of the tower. The separate pieces are first boiled in a strong solution of caustic soda and then washed with water from a hose, whereupon they are pickled with dilute sulphuric acid until

all the rust is dissolved. They are next thoroughly cleaned with steel brushes and water, and are then ready for plating. Inside surfaces, which do not require any plating, are protected by paraffine wax. The total thickness of the metallic coat is from $\frac{1}{32}$ to $\frac{1}{16}$ in. Mr. J. D. Darling was placed in charge of the plating.

Statuary Work.—All this work, as mentioned before, is of bronze, composed of 88 parts of copper, 10 parts of tin, and 2 parts of zinc. The several pieces forming a single figure or group are rigidly united by means of flanges about $3\frac{1}{2}$ ins. wide and $\frac{3}{4}$-in. and $\frac{7}{8}$-in. bolts, spaced not more than about 6 ins. apart. The metal averages about $\frac{3}{8}$ in. thick, but in the lower extremities of the figures it is made considerably heavier. No inside braces are used. The patterns for the foundry are of plaster of paris.

Erection.—The scaffolds to be used in the erection of the tower are of different design, and are now all completed, with the exception of that to be used in the erection of the Penn statue. This one has not yet been designed.

Owing to the complex nature of the structure, both the wrought-iron constructions and the shell complete were erected in sections in the company's yard. The first section is represented by the prism, the second by the four lower stories of the pyramid, up to the balcony, and the third by the rest of the tower. Generally speaking, the final erection is merely a repetition of the preliminary erection at the shops. The tower shell has been put together with open joints by inserting at short intervals small sheet-iron filling pieces of about the same thickness as the plating. In the final erection the shell will be made watertight by the use of usudurian. Brass bolts, with countersunk heads on the outside, will be used for the shell.

Since the top of the stone tower projects but a few feet beyond the base of the metallic prism, a working platform of timber (Plate XXXIV) has been provided at this level. This platform is in ground-plan a square of about 100-ft. sides, with the corners cut off. It serves, not only as a floor for the erecting gang, but also as a protection against damage to persons or property below from falling tools, etc. It is carried by 16 trussed flitch beams, acting as cantilevers. These beams are composed each of two timbers, 18 ins. by 7 ins. thick, having an iron plate between them bolted together by $\frac{7}{8}$-in. bolts. Eight of these beams, as shown in the plan, are 50 ft. long, and the

others 42 ft. In the longer beams the 18-in. iron plates are 1 in. thick, in the shorter ones $\frac{7}{8}$ in. The beams are arranged radially, as shown, and their inner ends are joined by an iron ring 19 ft. in diameter. 32 $1\frac{3}{8}$-in. square vertical rods, two for each beam, take hold of a pair of plate girders (originally built for another purpose), by means of a framework of 10-in. I beams; but since these plate girders do not extend into the walls they are connected by vertical rods with another pair of plate girders, situated some 60 ft. below the top of the stone tower and built into the walls of the tower. The flitch beams are braced laterally, as shown, and in order to protect the platform against vertical vibrations the inner ends of the flitch beams are supported by wooden posts, resting upon the brick arches of the masonry of the tower, while guy lines extend from the outer ends of the flitch beams to the masonry of the tower below, where they are secured by adjustable bolts. The platform has an inclination of $\frac{1}{4}$ in. in 1 ft. to provide for drainage, and is enclosed by a very substantial railing about 8 ft. in height, provided with a wire netting. The dimensions can readily be taken from the drawing.

In erection, the steam hoisting machine used in constructing the masonry portion of the tower is employed; the end of its horizontal beam is directly over the center of a trap-door in the platform through which all working pieces pass before being distributed over the floor.

The wrought-iron prismatic construction, as already mentioned, is now in place. The scaffolding for erecting the shell of the prism will rest upon this platform. The lower sections of the shell, however, cannot be assembled until after the platform has been removed, because the flitch beams of the platform penetrate the sides of the prism. The four statues, which are to stand upon the skeleton columns at the corner of the tower, can readily be picked up in sections by a derrick standing on the first floor. In erecting the four lower stories of the pyramid a scaffolding is used. This will be carried by the eight cantilevers of the first floor. It carries at its top a revolving derrick, which is indicated in dotted lines on the general design. The tower shell will be put in place after the mounting of the statue of William Penn. When all of the wrought iron is assembled up to the balcony, the derrick will be removed and a scaffolding from 75 to 80 ft. high, shown by dotted lines in the general design, erected.

The balcony brackets, which form a part of the trussed rafters, have been designed to carry this scaffolding, each leg of which will be anchored down by two 1¾-in. round bolts. The scaffold is an eight-sided prism of 20 ft. outside diameter, and, since all the space inside of it is needed, the wind bracings should be placed on the outside of the scaffold. A hoisting apparatus will be placed on top of it, and the material raised will pass up inside the tower, the scaffold acting as a cage. In order to economize working space only six of the eight rafters of the pyramid will first be put in place, together with the tower-cap and the ground-plate for the statue, which will then be raised in sections. Finally, the remaining two rafters, the rings and the diagonals will be inserted.

Two light platforms of timber, 3 ft. wide and about 18 ft. long, suspended from the revolving derrick, have been used in putting together the shell of the pyramid, and these will again be employed in the final erection. The diagram (Plate XXXII) of the false work, used in erecting the pyramid, shows the horizontal timbers nearly on the same level with the primary rings.

This arrangement has been made to provide for working floors to be carried by the horizontal timbers and the rings. These floors, together with the suspended platforms, enable the erecting gang to reach any point of the shell, either inside or outside.

After the large platform and the steam hoisting machine have been removed, the bottom sections of the shell will be put in, and this will complete the work of erecting the tower.

Material.—The tower framework is of wrought iron. All pins and the anchor bolts for the statue of William Penn are of steel.

The shell is of cast iron, with the exception of the louvres, which are made of steel plates.

The statuary work is of bronze.

Loads.

Dead Loads.—The tower has been proportioned to carry the following loads, viz. :

The primary framework carries its own weight and that of three floors, the balcony, the secondary construction and shell of the pyramid and the statue of William Penn.

The secondary construction of the prism carries its own weight and

that of the greater part of the shell of the prism, four statues and four eagles.

The remainder of the shell of the prism is carried directly by the masonry.

Live Loads.—Each of the three floors and the balcony have been proportioned to carry a load of 100 lbs. per square foot.

Wind.—Wind stresses have been calculated for a pressure of 50 lbs. per square foot, supposed to be acting horizontally against the shell, the surface of which, for this purpose, is regarded as vertical throughout, while the prismatic part of the tower has been treated as a four-sided prism, whose width equals the full diameter from out to out of the shell.

In order to compensate for the wind-pressure on the tall scaffolding standing upon the balcony, the placing of the shell of the pyramid will be deferred until after the removal of the scaffolding, so that the wind stresses during erection will be less than after the completion of the structure. Hence, these stresses have not been taken into account. All other stresses due to erection have been considered.

Working Stresses.

The writer allowed the following limits for the stresses per square inch in pounds, for the different members:

	Lbs.
Rolled bars in tension	15 000
Plates and shapes	12 000
Compression members, whose lengths are less than 50 times their least radii of gyration	10 000
Shearing across fibers	7 500
Bearing	12 000
Bending stress on pins	20 000
Shearing	10 000
Bearing	15 000

The bearing surfaces of pins and rivets have been reckoned from the diameter.

Compression members, whose lengths exceed 50 times their least

radii of gyration, have been proportioned according to the following formula:

Flat ends .... $S = \dfrac{10\,000}{1 + \dfrac{l^2}{36\,000\,r^2}}$

One flat end and one pin end .... $S = \dfrac{10\,000}{1 + \dfrac{l^2}{24\,000\,r^2}}$

Pin ends .... $S = \dfrac{10\,000}{1 + \dfrac{l^2}{18\,000\,r^2}}$

where S = allowable stress per square inch,

l = length in inches of member between supports,

r = least radius of gyration of cross-section.

The intensities of the working stresses for such members as are subjected to alternate stresses, are:

For tension .... $12\,000 \left(1 - \dfrac{1 \text{ min. stress.}}{2 \text{ max. stress.}}\right)$

For compression members, whose lengths are less than 50 times their least radii of gyration, $10\,000 \left(1 - \dfrac{1 \text{ min. stress.}}{2 \text{ max. stress.}}\right)$

For compression members, whose lengths exceed 50 times their least radii of gyration, the numerators in the above expressions have been reduced to $10\,000 \left(1 - \dfrac{1 \text{ min. stress.}}{2 \text{ max. stress.}}\right)$

No distinction has been made between the dead load and the wind stresses as far as the intensities of working stresses are concerned.

The minimum thickness of wrought iron is $\frac{1}{4}$ in., except in the more important members, where it is $\frac{5}{16}$ in. Field riveting will be avoided entirely, since at many places it is difficult to reach the rivets, and riveting would be surely unsatisfactory. The more important connections, such as rafter splices, etc., will be made by means of turned bolts, which have been given a slight taper to insure a tight fit. Minor connections will be made by rough bolts.

All tension members have been subjected in a testing machine to a stress of 20 000 lbs. per square inch.

Painting.—The wrought-iron construction has been given two coats of oxide of iron paint, and all surfaces coming in contact were painted before being riveted together.

Approximate Method of Computations.

The assumed dead weights for the tower complete are grouped as follows:

(1) Weight of wrought-iron construction for each story of the tower, including the weight of the secondary construction for the pyramid, and excluding same for the prism.

(2) Total weight of secondary construction of the prism.

(3) Weight of tower-cap.

(4) Weight of supporting girders.

(5) Weight of shell for each story of the pyramid.

(6) Total weight of shell for the prism.

(7) Weights of statuary work.

(8) Live weights.

All the above weights are given in tons.

The assumed wind forces, applied at the different stories and at the statue on the top, are also given in tons.

Dead Load and Live Load Stresses.—The dead weight affects all the members of the framework, except the diagonals and the rings of the primary construction in the prism and the diagonals of the pyramid. The determination of these stresses, together with those due to live load, is governed by well-known laws.

Wind Stresses—Stresses in Rafters.—In determining the wind stresses, the tower is considered to be a cantilever, fixed at the bottom. Passing a section through the tower, we apply the stresses in the members thus cut to maintain the equilibrium and compute the wind moment. If we now assume that the stresses in the rafters resist this wind moment, we can write an equation between these stresses and the moment of the exterior forces. Assuming further that the stresses in the rafters vary as their distances from the axis around which the wind moment has been taken, expressing the stresses in those rafters nearest the axis in terms of those farthest removed from the axis, and substituting these values in the original equation, we can easily find the maximum compression and tension.

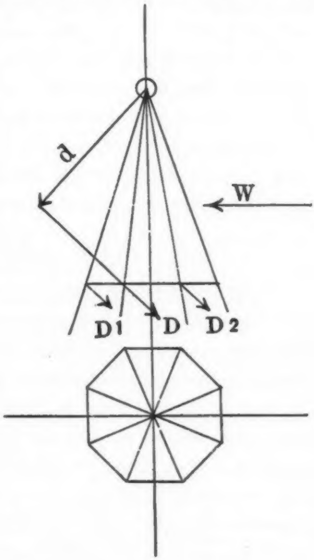
Stresses in Diagonals.—In computing the stresses in the diagonals we take as the center of moments the intersection point of the rafters and determine the wind moment around that center, which we will call M. With regard to the diagonals of the prism the center of moments is

removed to an infinite distance. The wind force will call into action only one system of diagonals, whose lever arms we denote by d (see sketch). The equation expressing equilibrium will then be:

$$M = 2D\,d + 2D_1\,d.\ \cos.\ 45^\circ + 2D_2\,d.\ \cos.\ 45^\circ:$$

In this equation the writer considered the sides of the pyramid as vertical.

Assuming now that the vertical components of the diagonals vary inversely as their distances from the axis of the tower, and expressing D_1 and D_2 in terms of D, we can find the stresses D in the diagonals from the above equation.



Stresses in Rings.—The rings take the horizontal components of the stresses in the diagonals.

Stresses in Wind Bracings.—If W denote the maximum wind force at any panel point, R the compression in a ring section; T the tension in a tie rod, we have—

$$R = \tfrac{1}{2}\ W \sec.\ 67\tfrac{1}{2}^\circ, \text{ and}$$

$$T = \tfrac{1}{2}\ W \text{ tg. } 67\tfrac{1}{2}^\circ.$$

Temperature Stresses.—Temperature stresses need not be considered, since the supporting box girders move on planed surfaces, and the construction is, of course, perfectly free to expand vertically upward.

The wrought and cast iron of the prismatic part of the tower have been weighed, and the assumed loads are found to agree fairly well with the actual weights, the former being but very slightly in excess.

Although all the wrought-iron and cast-iron work of the pyramid is done, none of the parts have thus far been weighed.

The estimated weight of 50 000 lbs. for the Penn statue proved nearly correct. The four statues on the skeleton columns have been assumed to weigh each 30 000 lbs., whereas the actual weight is only about 20 000 lbs. for each.

The total estimated weights for the tower are:

Wrought iron..............................	376 tons.
Cast iron	519 "
Statuary work..............................	105 "
Making a total of..........................	1 000 "
The total wind pressure amounts to.......	183.7 tons.

Since the overturning moment of the wind is one-half that due to the dead weight, it follows that a pressure of about 100 lbs. per square foot would overturn the tower, were it not for the resistance by the anchor bolts.

The approximate area of the tower-shell is 57 000 sq. ft., and it is believed that the structure, when completed, will be the heaviest metallic tower ever erected at such an altitude.

The approximate method of computations was used in designing the tall tower pyramid of the St. Petri Church in Hamburg, Germany, built from data by Schwedler and finished in the year 1878.

Exact Method of Computations.

In designing a rigid structure with superfluous bars, we must ascertain whether the structure would remain rigid after the superfluous bars are removed. Let us, therefore, consider what is the criterion for the statical determinateness and stability of trusses in space.

If a point of support of a figure in space cannot move in any direction whatever, we need three components in order to determine the reaction. These components may be conceived as the stresses in bars which connect the point of support with fixed points outside of the figure. In case a point of support is guided on a line, the stresses in two bars are required, and if a point of support is guided on a surface the stress in one bar is required.

For a truss in space let—

a = the number of joints in the truss.
n = " " bars in the truss itself.
p_3 = " " fixed points of support.
p_2 = " " points of support free to move on a line.
p_1 = " " points of support free to move on a surface.
m = " " n of bars in the truss itself plus those bars which act as points of support, as above explained.

We have then the equation—

$$m = n + 3\,p_3 + 2\,p_2 + p_1 = 3a.$$

If $m > 3\,a$ the truss has superfluous bars, and if $m < 3\,a$ the truss can change its shape.

But, although a structure cannot be statically determinate unless the above equation is satisfied, it must not be assumed that the satisfaction of this equation is the only necessary condition.

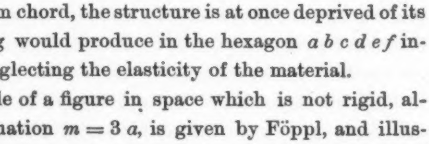
Two conditions are required in order to secure at the same time both the statical determinateness and the rigidity of a structure, and these two conditions may be expressed as follows:

If a truss in space is required to be statically determinate and of invariable form (1st) the equation $m = 3\,a$ must be satisfied, and (2d) the denominator determinant, formed by writing the coefficients of unknowns in a set of equations which express the equilibrium of the truss, must differ from zero.

For a plane figure the relation between the least number of bars and the number of apices is expressed by the equation $m = 2\,a$, and the same condition as to determinants must be fulfilled.

A mathematical proof of these assertions is hardly required, inasmuch as we can always form a judgment about the stability of a truss by computing the stresses and reactions which must be determinate quantities.

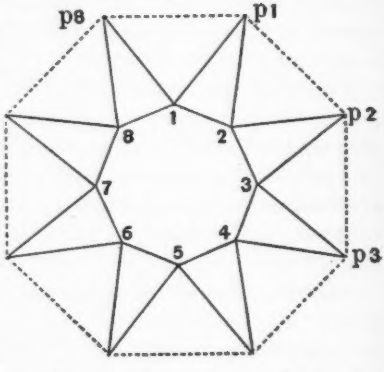
The truss shown in the sketch may serve as an illustration for a plane figure. This truss has one fixed and one loose end, and satisfies the equation $m = 2\,a$. Now, if we simply shorten the middle vertical $b\,e$ until the two top-chord sections $a\,b$, $b\,c$ come into one straight line, parallel to the bottom chord, the structure is at once deprived of its rigidity, and any loading would produce in the hexagon $a\,b\,c\,d\,e\,f$ infinitely great stresses, neglecting the elasticity of the material.



An interesting example of a figure in space which is not rigid, although satisfying the equation $m = 3\,a$, is given by Föppl, and illustrated in the sketch on page 266, $p_1\,p_2 \ldots\ldots p_8$ are fixed points of support of a frame having an even number of sides. It can easily be seen that the apexes 1, 3, 5, 7 can be raised the same amount as the

apices 2, 4, 6, 8 are lowered without the removal of a single bar. The apices are free to turn around the axes $p_1\, p_2$, $p_2\, p_3$, etc. But if the ring 1, 2, 3,......8 be given an odd number of sides, the figure is rigid.

The determination of the stresses by statics alone in a rigid truss having only the necessary number of bars does not always admit of a quick solution. On the contrary, it very often involves much labor, unless simplified methods can be discovered. In some cases the problem has been reduced to the computation of plane trusses. For instance, a pyramid with crossed tension diagonals in each panel, and which is open at the top and has no horizontal bracings, is a statically determinate structure. The same may be said if the sides of the structure stand upright, forming a prism. Such a statically determinate pyramid can be conceived as composed of as many plane cantilevers as the structure has sides, the cantilevers being fixed at the bottom. Let us now suppose that an exterior force is acting on any panel point, for instance of an eight-sided pyramid; we can then resolve this force into three components, one of them having the direction of the rafter, and the other



two the directions of the two adjacent ring sections. That component whose direction coincides with the center line of the rafter affects only the latter, while each of the other two components affects only that truss in whose plane it acts. From this it follows that the diagonal and ring stresses are independent of the rafter stresses, and that in those rafters on the leeward side which stand opposite to those on the windward side having maximum tension, the wind stresses are equal to zero.

The determination of the stresses in the tower by exact methods is extremely laborious. This is due to its statical indeterminateness which may be reduced, but it can not be entirely eliminated on account of the character of the demand upon the tower.

There is a general method which considers the laws of elasticity in

finding the stresses in a truss having a position in space and any number of superfluous bars, and which is based upon the principle of virtual velocities, a principle which has done such good service in connection with the theory of plane trusses.

An exposition of this principle and of its application to certain trusses can be found in a paper by Professor George F. Swain, M. Am. Soc. C. E., published in the Journal of the Franklin Institute for February, March and April, 1883, and in a paper by Professor William Cain, M. Am. Soc. C. E., "Determination of the Stresses in Elastic Systems by the Method of Least Work," *Transactions* of the American Society of Civil Engineers, 1891.

This method is as follows, assuming frictionless joints:

The general expression of the stresses S in any of the bars can be written as follows :

$$S = U + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \ldots\ldots\ldots\ldots\ldots (1)$$

In this equation X_1, X_2, X_3, ... represent the stresses in the superfluous bars, U represents the value of S under the assumption that the exterior forces act on the system of necessary bars alone; that is to say, the superfluous bars are supposed to be removed.

α_1 denotes the stress in any of the necessary bars by forces equal to unity, acting toward each other along the direction of X_1, assuming, as before, that all the superfluous bars are removed.

α_2 denotes the stress in any of the necessary bars by forces equal to unity, acting toward each other along the direction of X_2, assuming again that all the superfluous bars are removed.

The values α_3, α_4, ... are similarly defined.

The values U are independent of the unknowns X_1, X_2, X_3, ... and the values α_4, α_2, α_3 ...... are independent, both of the exterior forces and of the unknowns X_1, X_2, X_3, ...

The principle of virtual velocities in its application to trusses may be expressed as follows: The algebraic sum of the work of the exterior and interior forces, supposed to be in equilibrium and acting at the joints of a truss, is equal to zero in case of an indefinitely small deformation.

If we consider now the stresses α, and at the same time the virtual displacements, caused by the actual loading, and apply the above principle to this particular case, we arrive at the following equations for the determination of X_1, X_2, X_3......

$$\Sigma\, \alpha_1 \Delta l = o;\ \Sigma\, \alpha_2 \Delta l = o;\ \Sigma\, \alpha_3 \Delta l = o;\ldots\ldots\ldots\ldots (2)$$

In order to use these equations, we put—

$$\Delta l = \frac{S l}{E a}$$

or, in case temperature stresses are to be considered,

$$\Delta l = \frac{S l}{E \alpha} + e t l \text{.......................} (3)$$

In these equations—

$l =$ the length of a bar,

$E =$ the modulus of elasticity,

$a =$ the cross-section of a bar,

$e =$ the coefficient of extension or contraction due to a change in temperature,

$t =$ the uniform change of temperature in one and the same bar.

Substituting now in equation (3) the value of S from equation (1), and in equation (2) the value of Δl thus found, and writing, for brevity's sake—

$$\frac{l}{Ea} = w, \text{ we have—}$$

$$\Sigma \alpha_1 (U + \alpha_1 X_1 + \alpha_2 + X_2 + \alpha_3 X_3 + \ldots\ldots) w + \Sigma \alpha_1 e t l = o$$

$$\Sigma \alpha_2 (U + \alpha_1 X_1 + \alpha_2 + X_2 + \alpha_3 X_3 + \ldots\ldots) w + \Sigma \alpha_2 e t l = o$$

or—

$$\Sigma \alpha_1 U w + X_1 \Sigma \alpha_1^2 w + X_2 \Sigma \alpha_1 \alpha_2 w + X_3 \Sigma \alpha_1 \alpha_3 w + \ldots\ldots\ldots + \Sigma \alpha_1 e t l = o$$

$$\Sigma \alpha_2 U w + X_1 \Sigma \alpha_2 \alpha_1 w + X_2 \Sigma \alpha_2^2 w + X_3 \Sigma \alpha_2 \alpha_3 w + \ldots\ldots\ldots + \Sigma \alpha_2 e t l = o$$

These sums refer to the external bars, supposed to act at and replace the points of support, as well as to the necessary and superfluous bars.

We have now as many equations as unknowns X_1, X_2, X_3, ...in fact, we can always develop as many equations as we have superfluous bars, and consequently this last set of equations can be solved. After this is done we substitute in equation (1) the values of X_1, X_2, X_3, ... thus found and compute the stresses in any of the necessary bars.

By application of the principle of least work instead of that of virtual velocities we would obtain the same results.

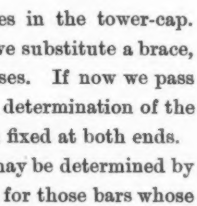
If, now, regarding those bars which take the place of the supports, we suppose them to be subjected to alterations corresponding to the

displacements of the points of support, we can then judge the effect of such displacements on the stresses in the structure.

We know that for certain investigations in connection with the theory of plane trusses it is sometimes of advantage to conceive of a group of bars as a whole, that is as one single plane and rigid figure or disc (German, *scheibe*) without regarding the relative positions of the bars which constitute the group. Professor Müller (Breslau) makes frequent use of such figures; as, for instance, in his investigations of Schwedler domes.

Since it is immaterial, so far as an investigation is concerned, whether the rafters are polygonal or straight, the frame we are considering may be treated in the same way as a Schwedler dome.

It will be remembered that the horizontal braces used in the tower are composed of eight tension members, acting in connection with an octagonal ring. Removing all eight tension members and inserting in their stead five bars (see sketch), capable of resisting compression as well as tension, we produce a rigid figure which performs its work just as well as the original system of bars. Any change in the arrangement of the bars constituting the original system, affects the stresses of these bars only, leaving the stresses in all the other bars unaltered, provided the original form of the octagon remains the same, for the virtual displacements of the apices are not affected by the means which we choose to effect the rigidity of the ring. These



considerations enable us to calculate the stresses in the tower-cap. The forces acting on the tower-cap are known, if we substitute a brace, as shown in the sketch, and compute all the stresses. If now we pass a section through the tower-cap at any point, the determination of the stresses will be the same as that of a curved beam fixed at both ends.

The effect of improper fitting on the stresses may be determined by employing the original equations and by assuming for those bars whose lengths are not exact a proper temperature which is added to or subtracted from or substituted for the original values of t. The alteration in the length of a bar whose temperature is raised $t_{,}$ degrees is $e\, t_{,}\, l$, and consequently, if a bar is too short by a quantity $= c\, l$, its temperature must be raised $\frac{c}{e}$ and the temperature of that bar, which is too

long by $c\,l$, must be lowered $\frac{c}{e}$. Assuming now the original temperatures of the bars after their insertion, we must attribute to those bars whose temperature has been raised, a change of $(-t_f)$ degrees, and to those whose temperature has been lowered, a change of $(+t_f)$.

Where a thorough knowledge of the conditions of a structure is required, all secondary stresses must be included in the investigation. Exact methods for finding secondary stresses, even in plane trusses are, comparatively speaking, of recent development ; while with regard to trusses in space this subject, so far as the writer knows, has hardly been touched upon by any author.

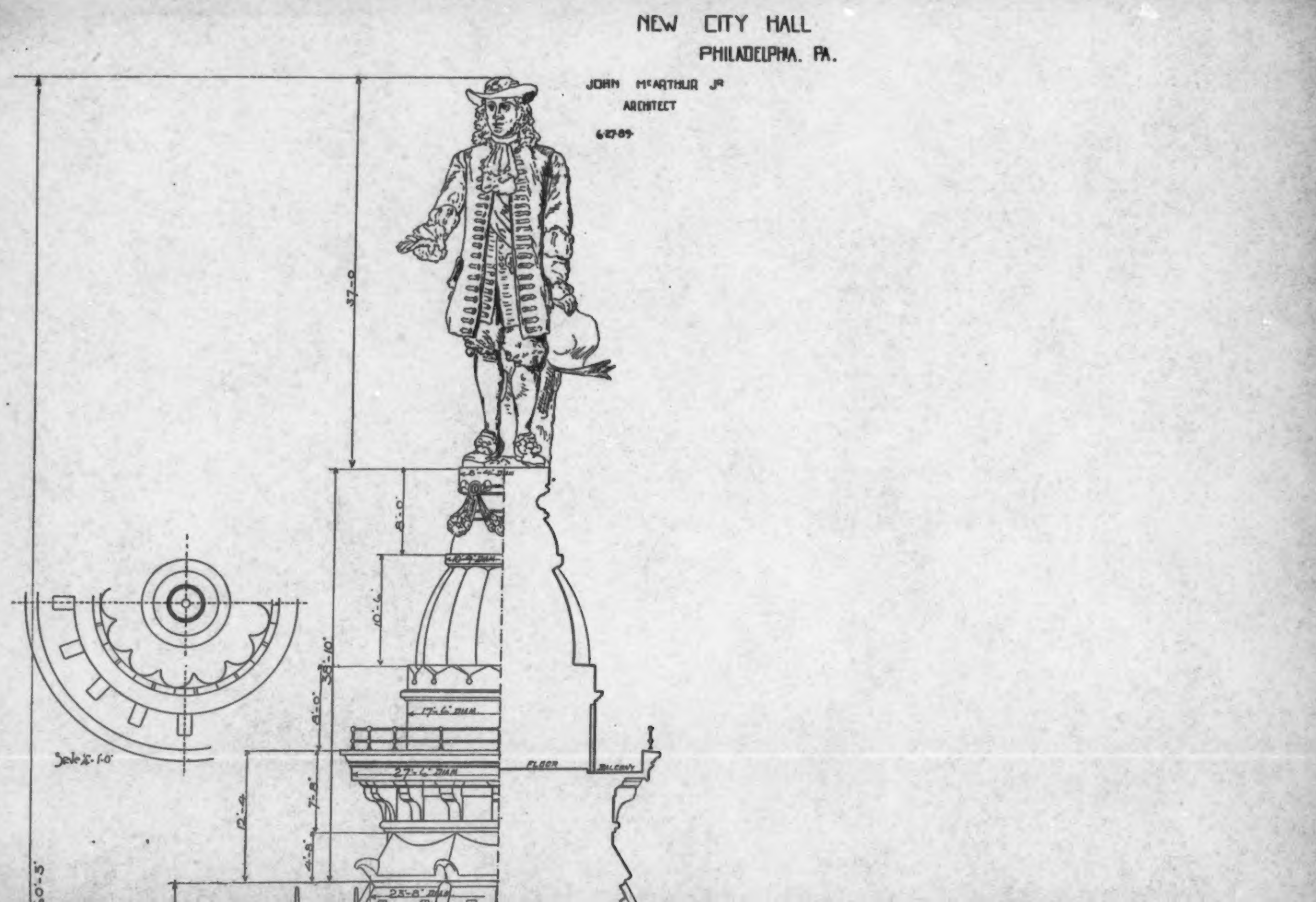
Such methods have the disadvantage that they require an estimate of the sections which are the object sought. It is therefore necessary to use some kind of an approximate method to determine the sections. These sections may then have to be changed, in order to comply with the results of the investigation, and if the changes thus required are of considerable extent, all the calculations may have to be repeated.

If we consider that the calculation of the secondary stresses due to yielding of the ground and to deformation of the masonry presents insurmountable difficulties, if we further consider that the modulus of elasticity in any given material is a quantity of uncertain amount, and that even our usual assumption as to the distribution of the dead weight is in many cases only approximately true, we see at once that the true stresses can never be computed, and that we must content ourselves with working stresses of lower intensities than would be permissible if the stresses could be accurately known. The writer would never advocate the adoption of trusses with superfluous bars, except in cases where they can be shown to have some marked advantage over others.

Since instruments are at our disposal by means of which we can ascertain alterations of less than $\frac{1}{1000}$ of 1 in. in the lengths of the bars, the surest way to find the true stresses would be to measure these alterations. From these the stresses can easily be computed.

The writer could not obtain an account of the cost of the tower, but to judge from general information he thinks the cost, inclusive of erection, will be from $650 000 to $700 000.

Believing that it will interest the members of this Society, the writer will give, in conclusion, a table showing, in the main, the hori-



NEW CITY HALL
PHILADELPHIA. PA.
JOHN McARTHUR Jr
ARCHITECT
6-27-89
37-0
8'-0'
10'-6
38'-10'
8'-0'
7'-8'
12'-4
4'-8'
17'-6' DIAM.
27'-6' DIAM
25'-8' DIAM
FLOOR
BALCONY
Scale ⅛"-1-0'

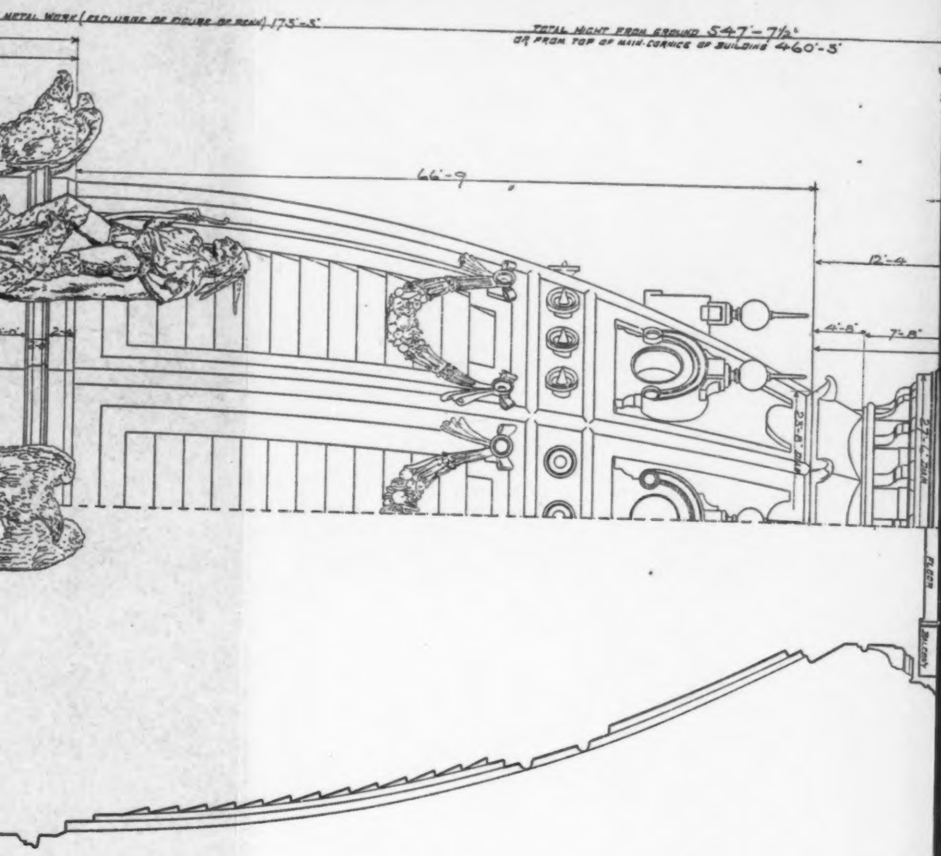

METAL WORK (EXCLUSIVE OF FIGURE OF PENN) 175'-5"
TOTAL HIGHT FROM GROUND 547'-7½"
OR FROM TOP OF MAIN CORNICE OF BUILDING 460'-5"
66'-9
12'-4
4'-8"
7'-8"
2'-4
23'-8" DIA.
27'-6" DIA.
FLOOR
BALCONY

PLATE XXXI.
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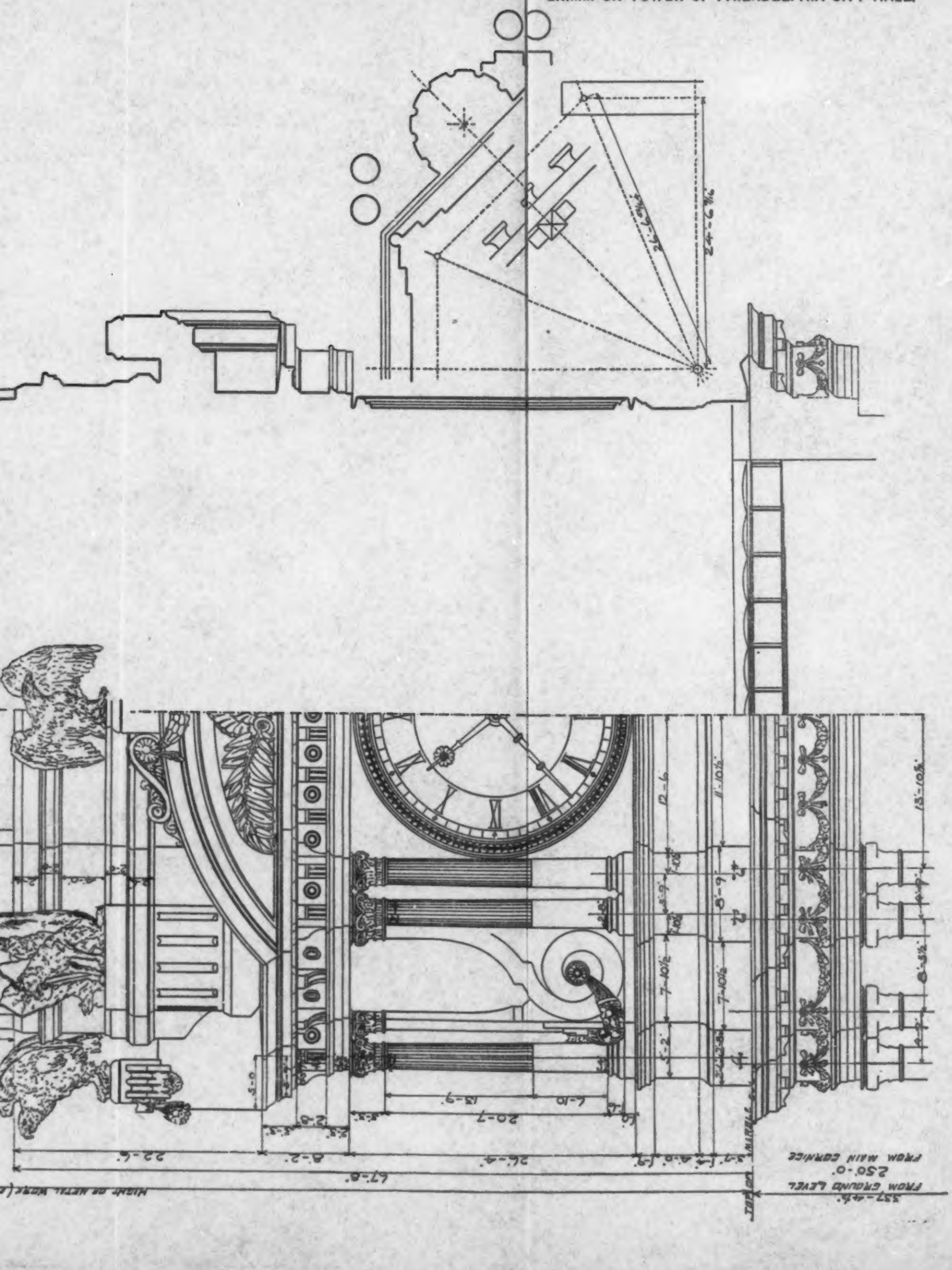
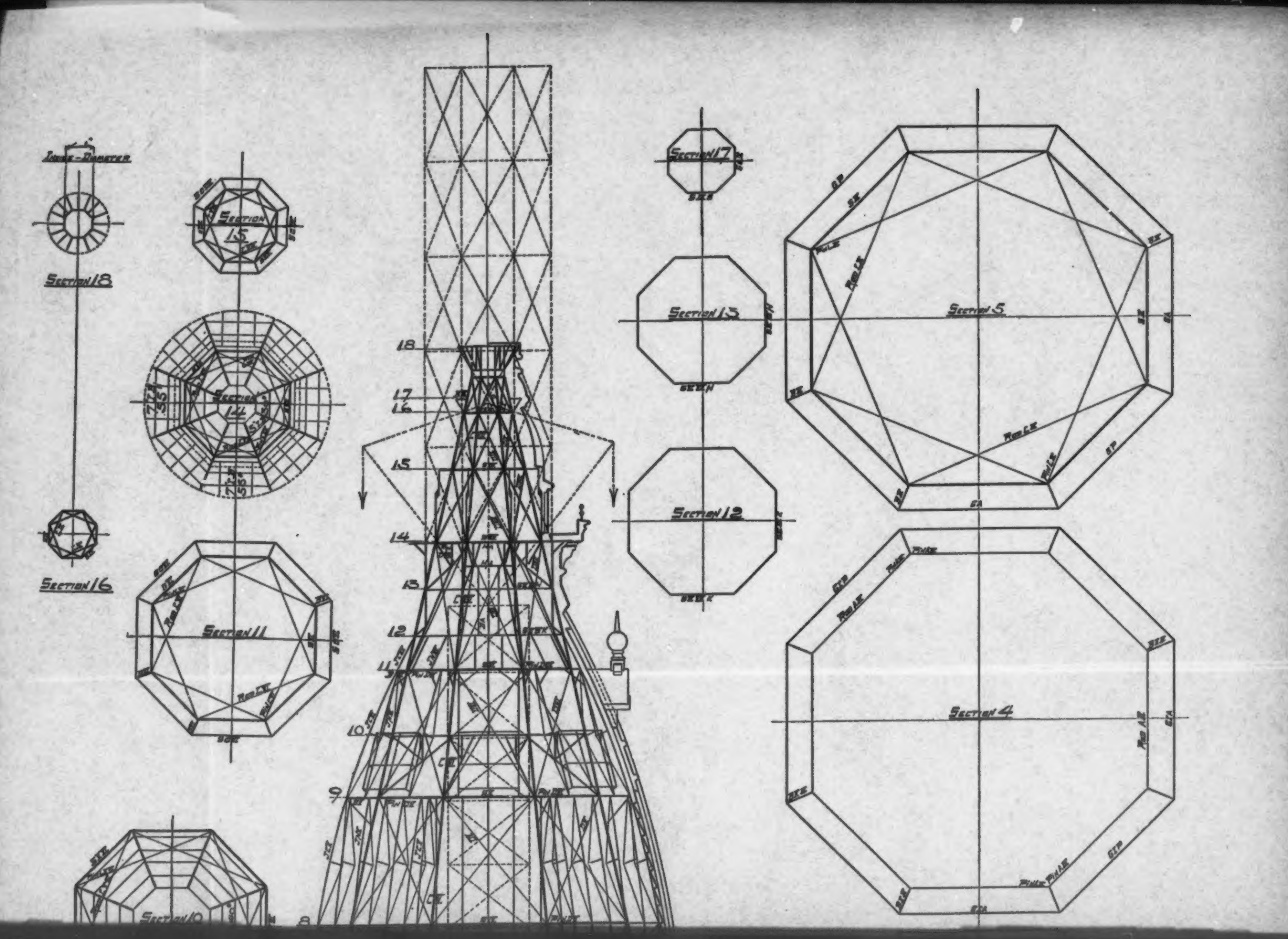
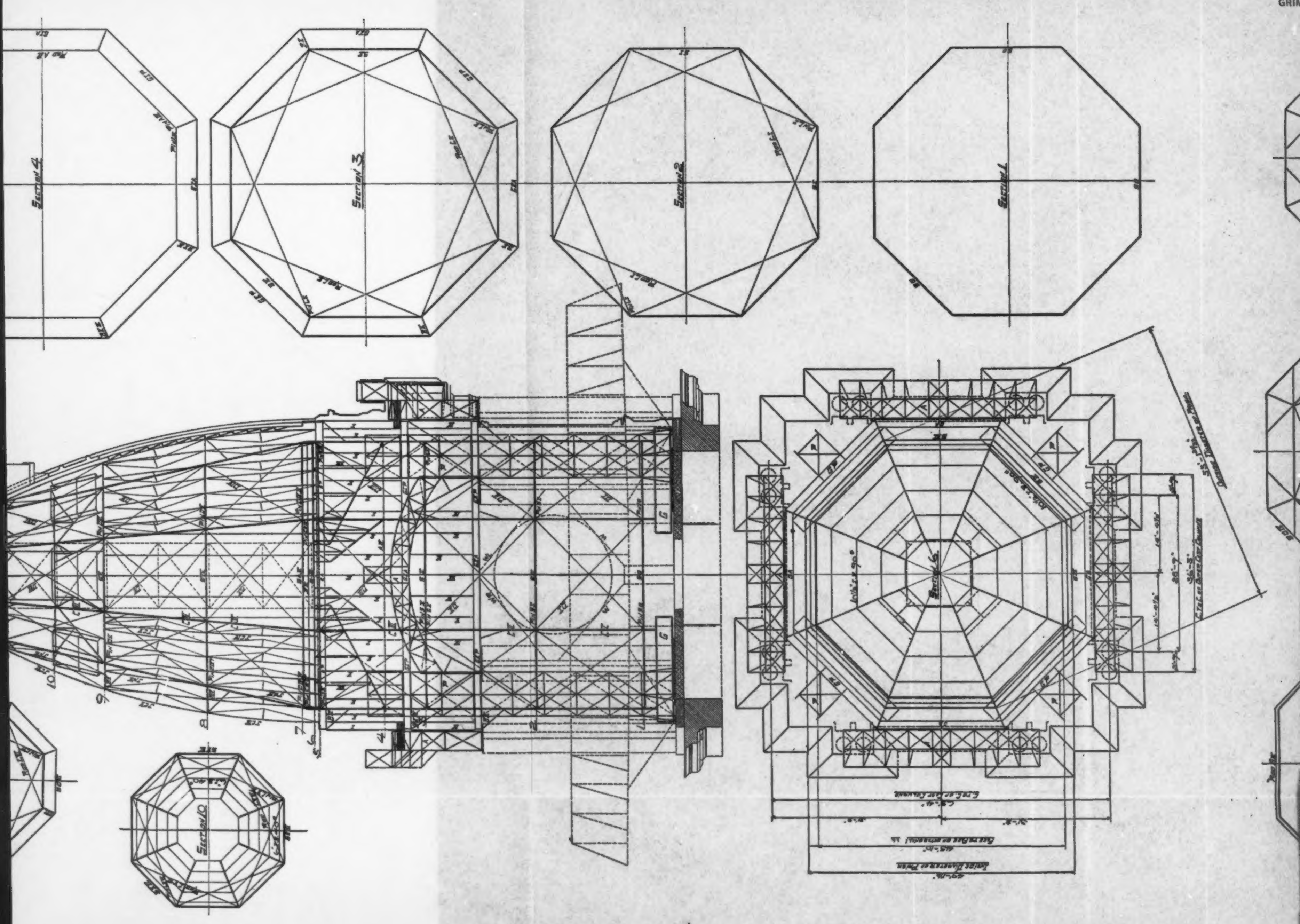
GRIMM ON TOWER OF PHILADELPHIA CITY HALL.





Inside-Diameter
Section 18
Section 15
Section 14
Section 16
Section 11
Section 10
Section 17
Section 13
Section 12
Section 5
Section 4
18
17
16
15
14
13
12
11
10
9
8

GRIM



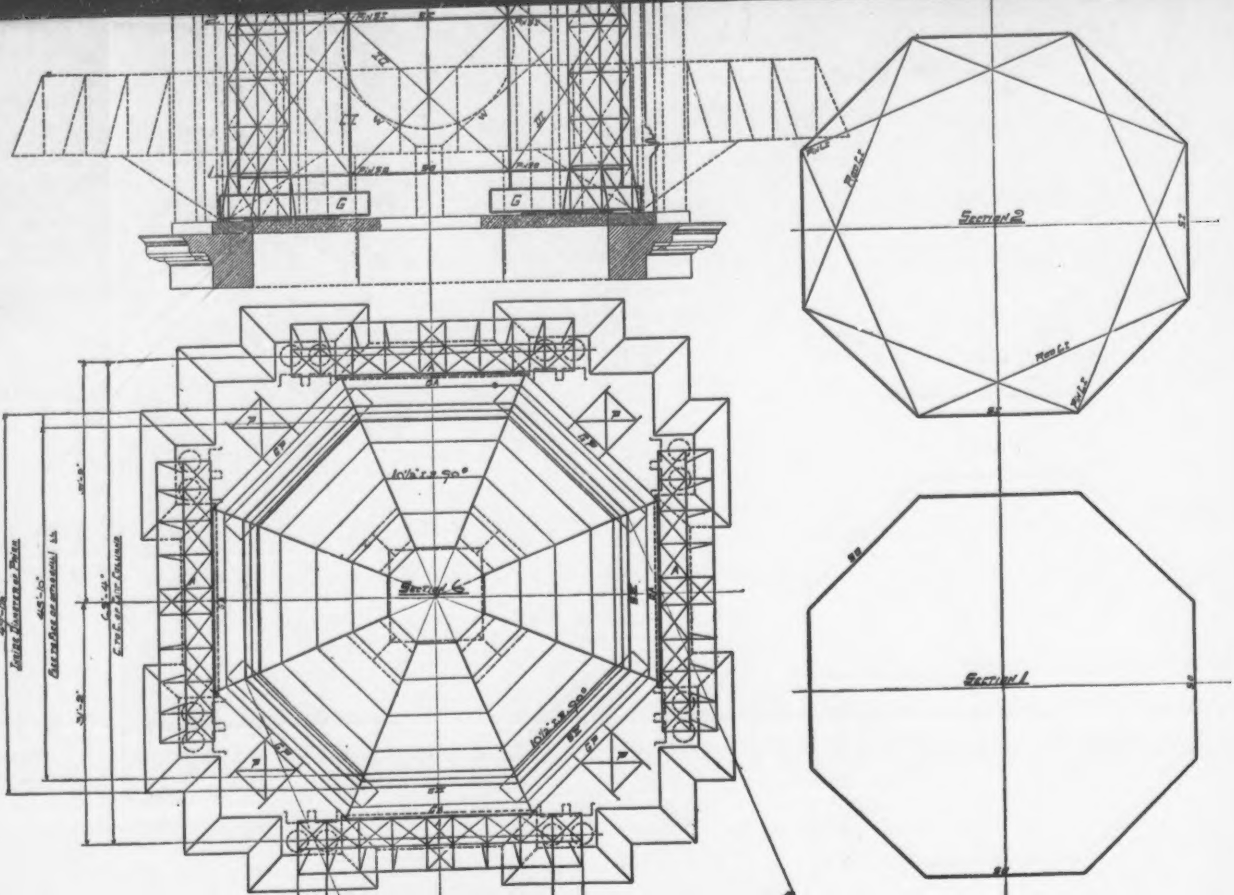

SECTION 2
SECTION 1
G
G

PLATE XXXII.
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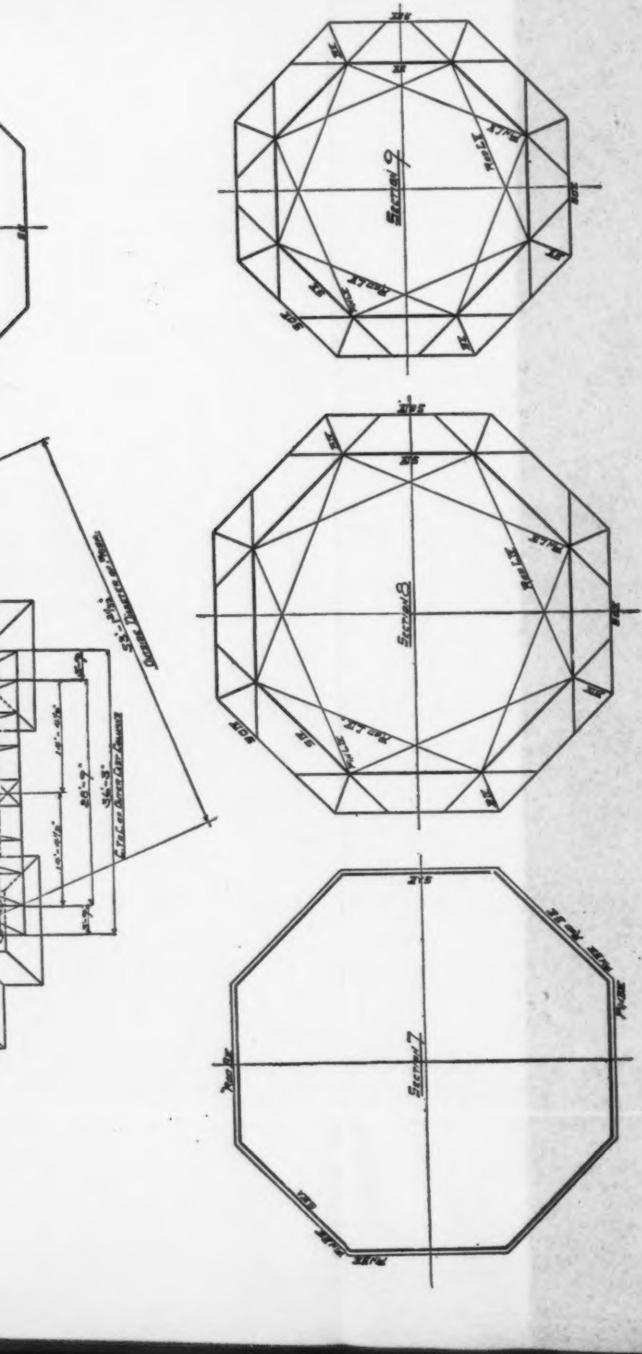
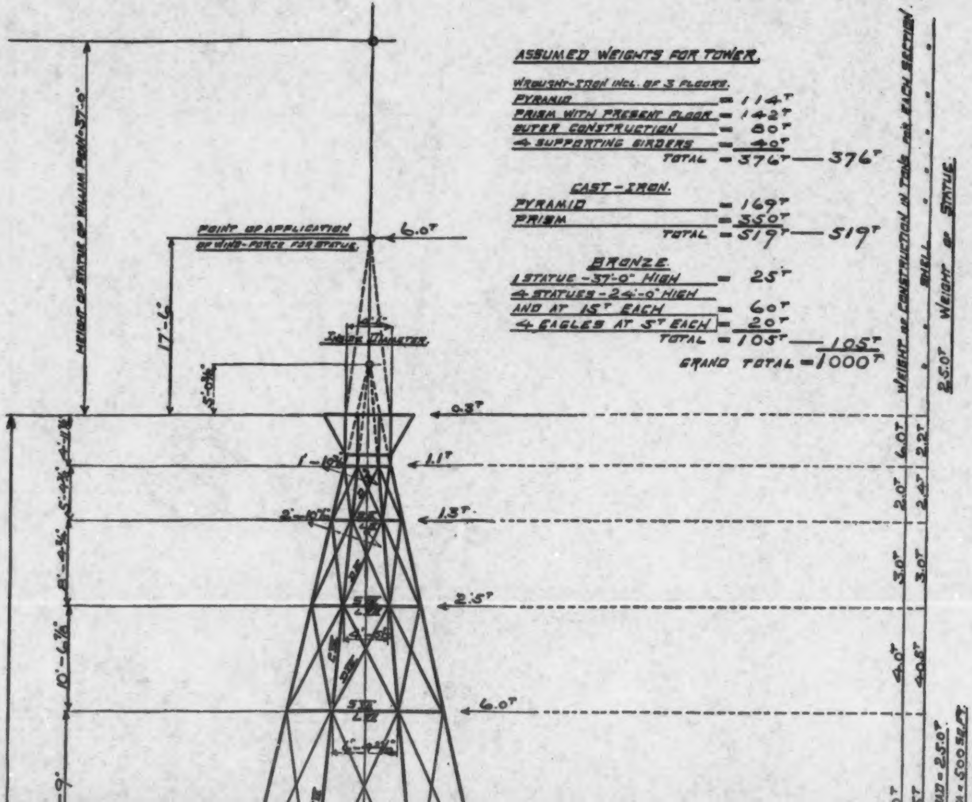
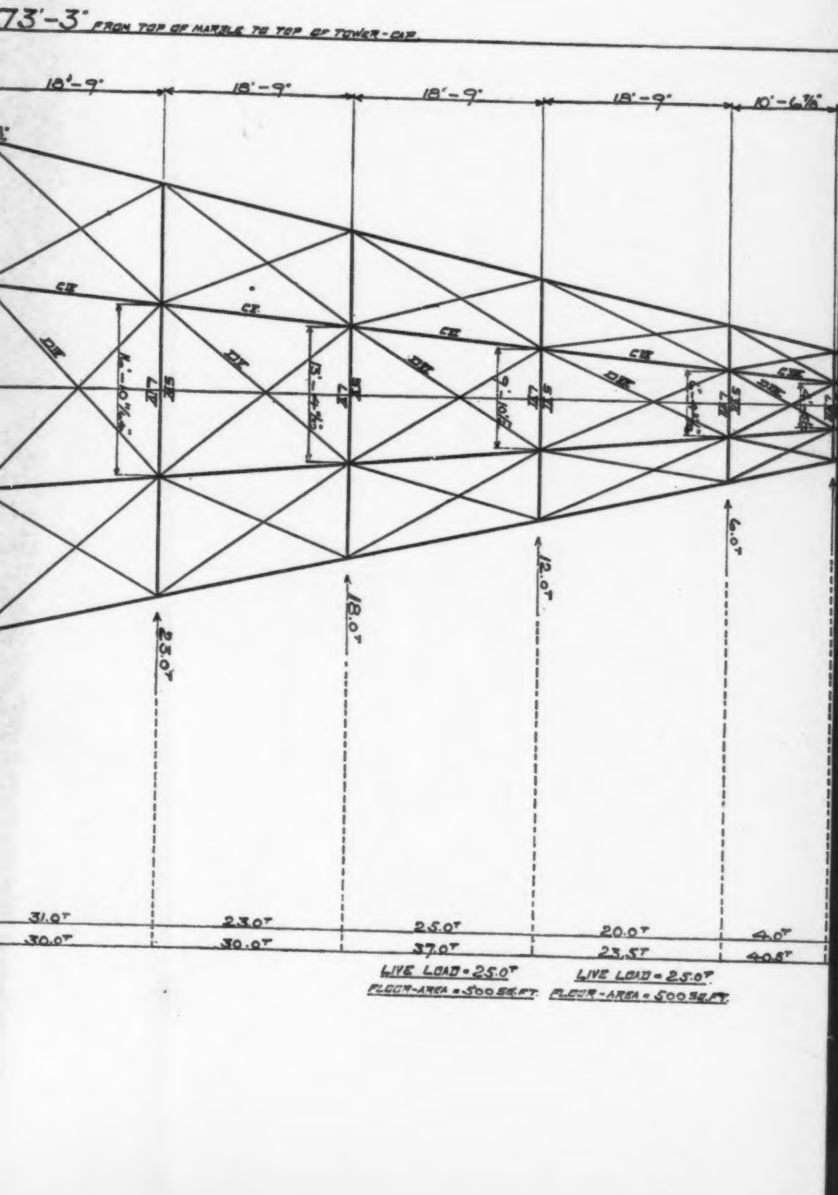
GRIMM ON TOWER OF PHILADELPHIA CITY HALL.




ASSUMED WEIGHTS FOR TOWER.
WROUGHT-IRON INCL. OF 3 FLOORS.
PYRAMID = 114T
PRISM WITH PRESENT FLOOR = 142T
OUTER CONSTRUCTION = 80T
4 SUPPORTING GIRDERS = 40T
TOTAL = 376T — 376T
CAST-IRON.
PYRAMID = 169T
PRISM = 350T
TOTAL = 519T — 519T
BRONZE.
1 STATUE - 37'-0" HIGH = 25T
4 STATUES - 24'-0" HIGH AND AT 15T EACH = 60T
4 EAGLES AT 5T EACH = 20T
TOTAL = 105T — 105T
GRAND TOTAL = 1000T
POINT OF APPLICATION OF WIND-FORCE FOR STATUE.
6.0T
17'-6"
5'-0¾"
INSIDE DIAMETER.
HEIGHT OF STATUE OF WILLIAM PENN - 37'-0"
0.3T
1.1T
1.3T
2.5T
6.0T
1'-10½"
2'-10½"
4'-11¾"
5'-4¾"
8'-4¾"
10'-6⅞"
WEIGHT OF CONSTRUCTION IN TONS FOR EACH SECTION.
6.0T
2.0T
3.0T
4.0T
SHELL
2.2T
2.4T
3.0T
4.05T
25.0T WEIGHT OF STATUE.



73'-3" FROM TOP OF MARBLE TO TOP OF TOWER-CAP
18'-9"
18'-9"
18'-9"
18'-9"
10'-6 7/8"
23.0T
18.0T
12.0T
6.0T
31.0T
30.0T
23.0T
30.0T
25.0T
37.0T
20.0T
23.5T
4.0T
40.5T
LIVE LOAD = 25.0T
FLOOR-AREA = 500 SQ.FT.
LIVE LOAD = 25.0T
FLOOR-AREA = 500 SQ.FT.

PLATE XXXIII.
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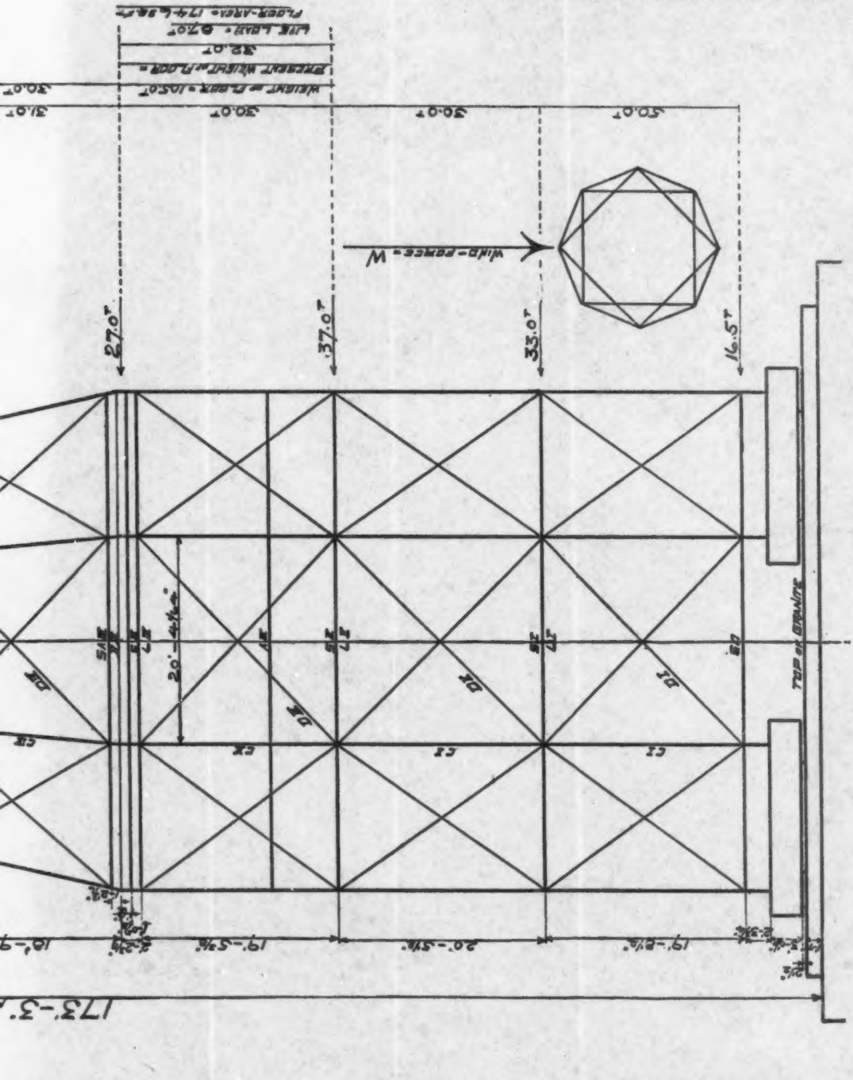
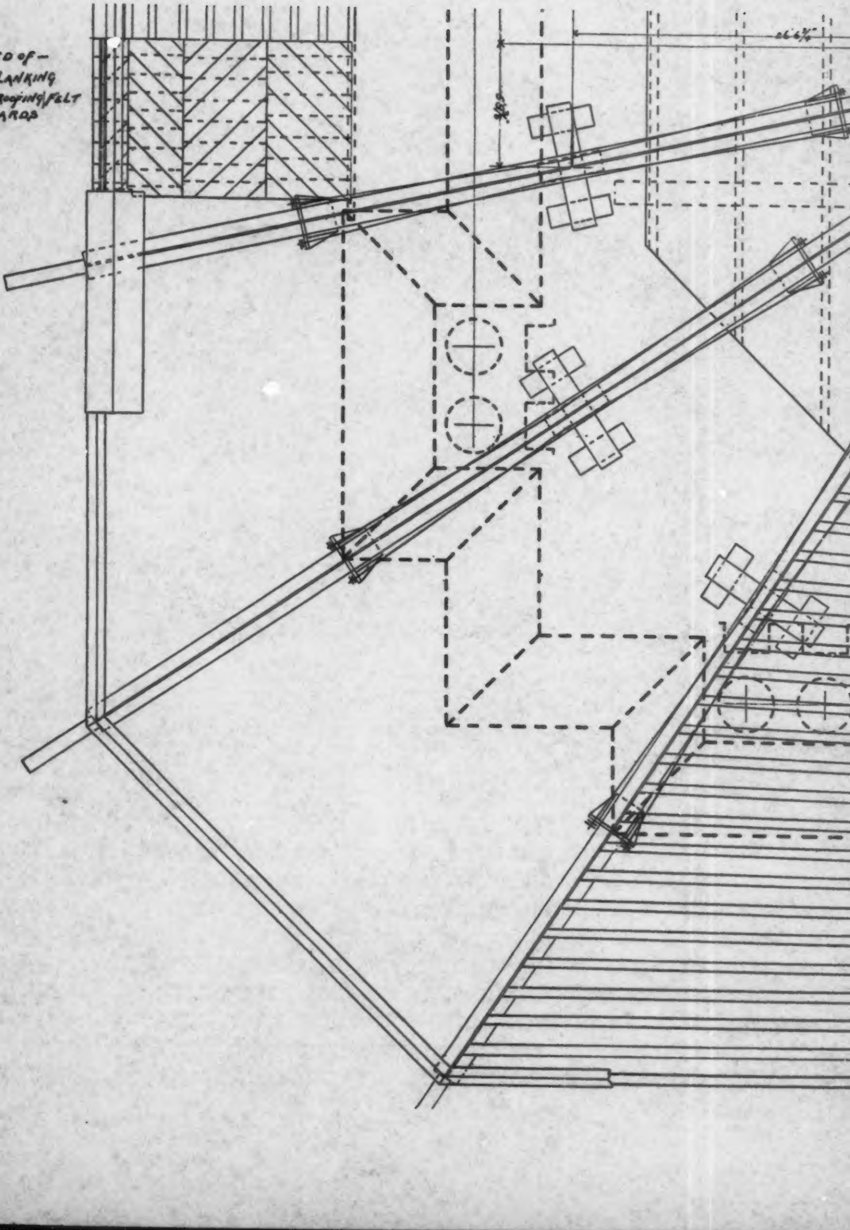
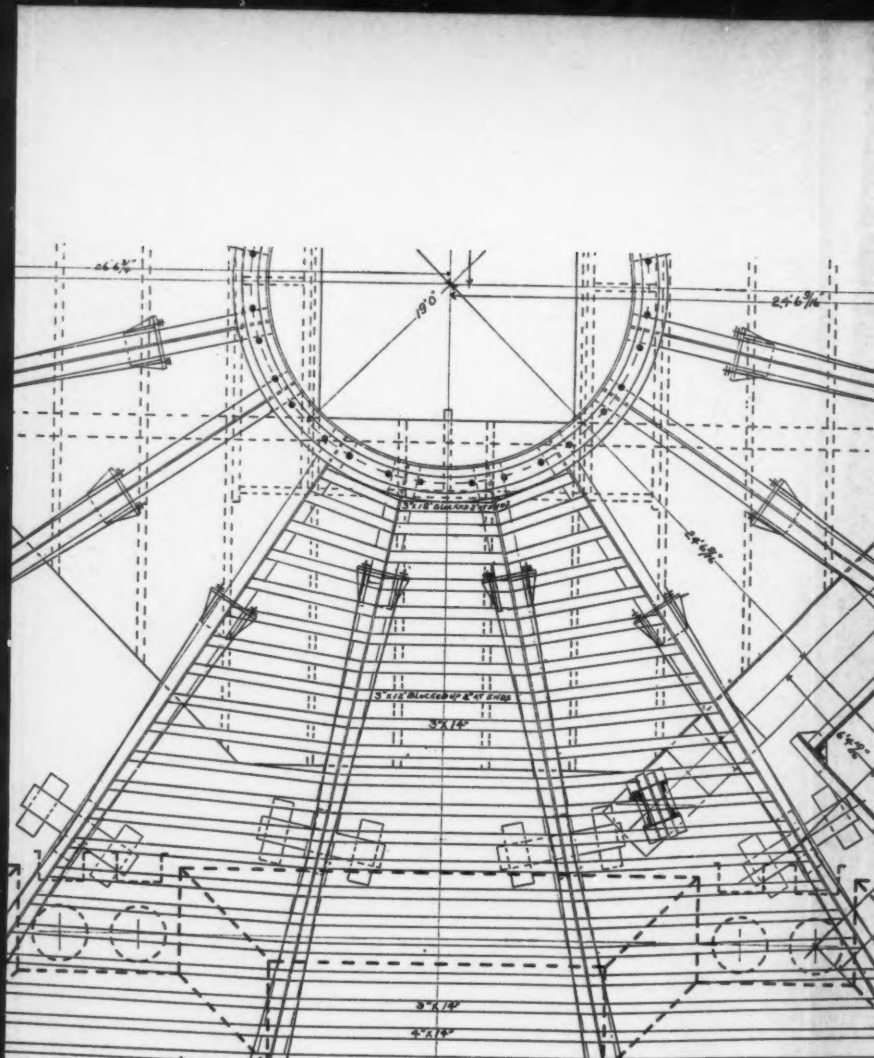
GRIMM ON TOWER OF PHILADELPHIA CITY HALL.



FLOOR COMPOSED OF —
2" YELLOW PINE PLANKING
2 THICKNESSES OF ROOFING FELT
1 3/4" FLOORING BOARDS





19'0"
24'6 9/16"
3"x12" BLOCKED UP 2" AT ENDS
3"x14"
3"x14"
4"x14"
4"x14"
6"x14"

PLATE XXXIV.
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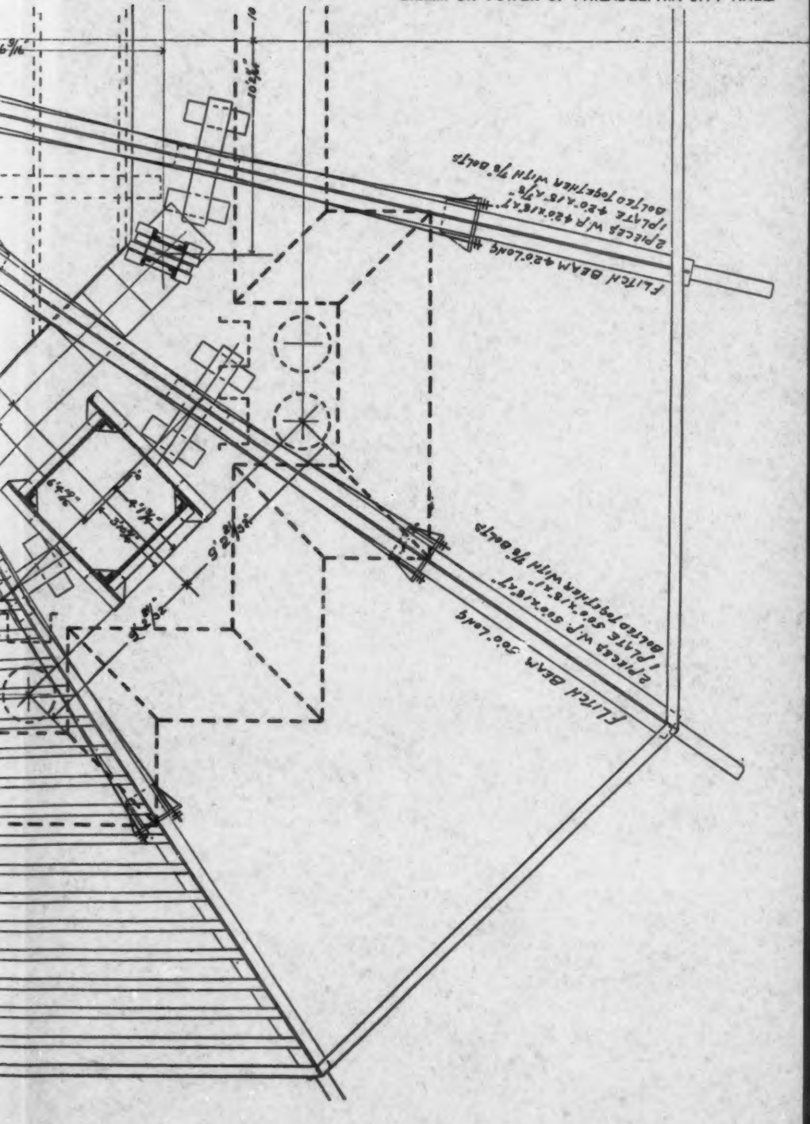
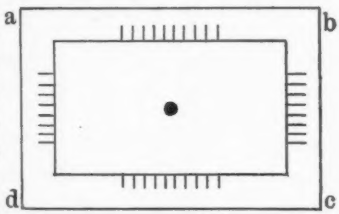
GRIMM ON TOWER OF PHILADELPHIA CITY HALL.



zontal deflections of the masonry tower under the influence of the sun. The readings, with respect to the deflections and temperatures were, as a rule, taken three times a day, excepting Sundays, and were commenced on the 1st of March, 1892. The table covers a period of one year from that date to the 1st of March, 1893. The maximum, minimum and average movements, north, south, east and west, as also the number of movements, are given for each month. The table shows also the maximum, minimum and average temperatures, as also the number of temperature observations, for each month. The temperatures were taken inside the tower at a point 230 ft. below the top of the stone work. The deflections were measured by means of a plumb line 230 ft. long, consisting of a heavy weight and a thin piano wire, suspended from a point at the center of the top of the stone tower. The plumb line at its lower end passes through a small, rectangular, wooden frame *a b c d*. This frame rests on a wooden box, containing molasses, into which the weight of the plumb line is immersed. Each side of the frame is divided in the neighborhood of its center into thirty-seconds of an inch. By the use of a steel straight-edge the deviations were easily ascertained.



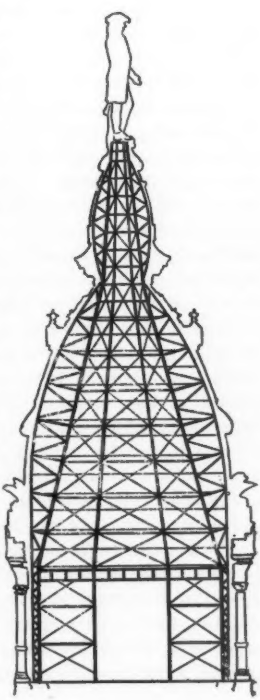
Since the stone tower is 337 ft. 4½ ins. high, we should add about 47% to the deviations, in order to obtain those for the total height.

MOVEMENTS OF THE MASONRY TOWER IN INCHES.

	NORTH.			SOUTH.			EAST.			WEST.		
	Max.	Min.	Average.	Max.	Min.	Average	Max.	Min.	Average.	Max.	Min.	Average.
1892.												
March	$\frac{3}{16}$	$\frac{1}{32}$	$\frac{5}{64}$	$\frac{3}{16}$	$\frac{1}{32}$	$\frac{5}{64}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{3}{64}$
April	$\frac{9}{32}$	$\frac{1}{32}$	$\frac{3}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{3}{64}$
May	$\frac{7}{32}$	$\frac{1}{16}$	$\frac{11}{64}$	0	0	0	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{3}{64}$
June	$\frac{9}{32}$	$\frac{1}{16}$	$\frac{11}{64}$	0	0	0	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
July	$\frac{3}{8}$	$\frac{1}{16}$	$\frac{5}{32}$	0	0	0	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{1}{16}$
August	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{3}{16}$	0	0	0	$\frac{3}{16}$	$\frac{1}{32}$	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
September	$\frac{5}{16}$	$\frac{1}{16}$	$\frac{5}{32}$	0	0	0	$\frac{5}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
October	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{8}$	0	0	0	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{16}$	0	0	0
November	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{3}{16}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{9}{64}$
December	$\frac{5}{64}$	$\frac{1}{32}$	$\frac{5}{64}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{5}{64}$
1893.												
January	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{1}{32}$	$\frac{5}{64}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{16}$	$\frac{1}{32}$	$\frac{3}{64}$
February	$\frac{5}{32}$	$\frac{1}{32}$	$\frac{5}{64}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$

Number of the observations of movements.				Temperatures.			Number of the observations of the temperatures.
North.	South.	East.	West.	Max.	Min.	Average.	
29	40	24	24	58	24	40.5	65
68	1	41	9	78	39	54	78
72	0	30	7	82	52	65.5	78
76	0	64	2	90	64	78	76
73	0	46	7	98	64	80	73
76	0	61	3	93	70	79	77
76	0	54	1	88	58	70.8	76
74	0	56	0	78	44	60.5	78
55	14	66	2	67	29	47.6	78
62	4	19	11	64	16	35.8	81
5	52	6	37	44	2	26	78
32	19	12	17	54	14	36.4	72

DISCUSSION.



JOSEPH M. WILSON, M. Am. Soc. C. E. (by letter).—At the request of Mr. John McArthur, architect, City Hall, Philadelphia, I did a considerable amount of expert work for him in 1880 to 1883 on the proposed tower for the City Hall.

I had the weights and pressure per square foot computed for the several horizontal sections of the tower, which I reported to him in April, 1880, with recommendations, and it was on my recommendation that he reduced the weight by changing the upper portion of the work, as originally designed, to iron, and also making some changes in the thickness of the walls below.

I also made a design for a skeleton iron construction for the upper part of the tower and furnished him with general drawings for this work, which were sent to him on May 7th, 1880.

The design was adopted by Mr. McArthur and placed on his drawings. The framework of this design was of entirely open construction, consisting, for the lower portion, of an octagonal prism, and, for the upper, an octagonal pyramid, the inner or heavy skeleton being the pri-

mary, and the outer or light one intended to support the shell, both being braced together. The entire interior is open, with a floor on girder construction at the junction between the octagonal prism and the pyramid.

Not having seen Mr. Grimm's drawings I do not know how the two designs compare, but I submit this as perhaps an interesting item in the history of the work on this tower.

We (Wilson Brothers & Co.) designed the crane and accompanying machinery used in the erection of the stone work of this tower, and also the high false works used at the central entrances of the building during construction.

I have designed and had constructed several roofs covering spaces nearly square in shape, 80 to 90 ft. square, in which the thrust was taken by ties around the exterior walls, there being no ties crossing the space covered. Among these I might mention the central part of Machinery Hall, Centennial Exhibition, where nave and transepts crossed, and the main waiting-room of the former passenger station of the Pennsylvania Railroad at Jersey City. The main rafters were placed on the diagonals of the square, meeting at the apex of the roof, and the construction formed what might be called a square dome, the whole space being left open up to the roof.

George Hill, Assoc. M. Am. Soc. C. E.—The designing and erection of towers is so common an occurrence, that the interest therein is less in the principles than in the application thereof. In the present instance, it would seem as though certain precautions had been neglected. If I correctly understood Mr. Grimm, the sizes of the members for the preservation of the form of the tower in plan were determined arbitrarily, which in so important a construction, and especially one of such size in plan, would seem to be a wholly unnecessary compliance with an unreasonable architectural requirement.

The construction of the tower in two parts, one intended to resist the wind and other loads, and the other simply to carry the covering of the tower, is such as to inevitably give rise to different amounts of expansion between the two, when subjected to the sun's heat, the outer shell, which is directly bolted to its supports, being warmed to a much higher temperature than the inner or main portion. If the tower is 175 ft. high, the approximate amount of expansion would be $1\frac{3}{4}$ ins., and if we should assume that the outer portion expanded twice as much as the inner one, which would seem to be reasonable, there would be a difference between the two of $\frac{7}{8}$ in., which would have to be accommodated either by springing the connecting brackets, or else by wrinkling and buckling the thin cast-iron shell; and this would, inevitably, lead to very annoying leaks if to nothing more. In my own experience, I have known of rafters 20 ft. long in a mansard roof, covered with fire-proofing and then with copper, to expand and contract

under the influence of the sun, coming on for a few hours near noon, and then passing off a sufficiently great amount to crack the plaster where the mansard joined the side walls, indicating a movement of $\frac{1}{16}$ in. It would seem as though the same care which dictated the plating of the tower with aluminum would have provided for the free motion of the covering.

A final point would be to question the advisability of using any untried material for the making of a joint under such trying conditions. Long experience with rubber as an insulating medium on electric lighting wires has shown the great difficulty of obtaining anything which is permanent in its character, which would at once raise the question as to the life of any cement with rubber as an essential part. In addition to this, bitter personal experience has shown me that in important constructions it is not enough that a material should apparently contain all of the elements that are desirable, but we should go further and have proof of its satisfactory operation under analogous conditions.

Mr. J. A. McDonald, M. Am. Soc. C. E.—Nothing has been said in this paper, so far as I am aware, about the factor of safety allowed for wind pressure. It is stated that the stresses have been calculated for 50 lbs. to the square foot. It is very important that we should consider the question of the greatest allowable stresses on such structures. You might get the 50 lbs. per square foot three times in a year, or, perhaps, once in a lifetime, and, therefore, towers exposed to wind pressure only should be treated differently to structures subject to other loading, and not have the same factors of safety. The stresses do not alternate rapidly, and the maximum stresses are so seldom, if ever, attained, that it appears to me we might apportion our material very closely up to the elastic limit. The question, I think, for engineers to decide is, how close it would be safe to go towards the elastic limit of the material with a structure which is stressed chiefly by wind pressure.

The paper does not give how closely the calculated stresses come to the elastic limit of the material. I think, as I said before, that in these structures we might apportion our material to come very close indeed, to the elastic limit of the material itself.

J. Foster Flagg, M. Am. Soc. C. E.—I would like to ask one question. I understand that the shell of the dome is first coated with copper and then with aluminum. Is there any difficulty in depositing aluminum directly on iron, or for what other reason is copper used?

Was it necessary to first coat the surface of the iron with copper in order to secure a firm attachment of the aluminum?

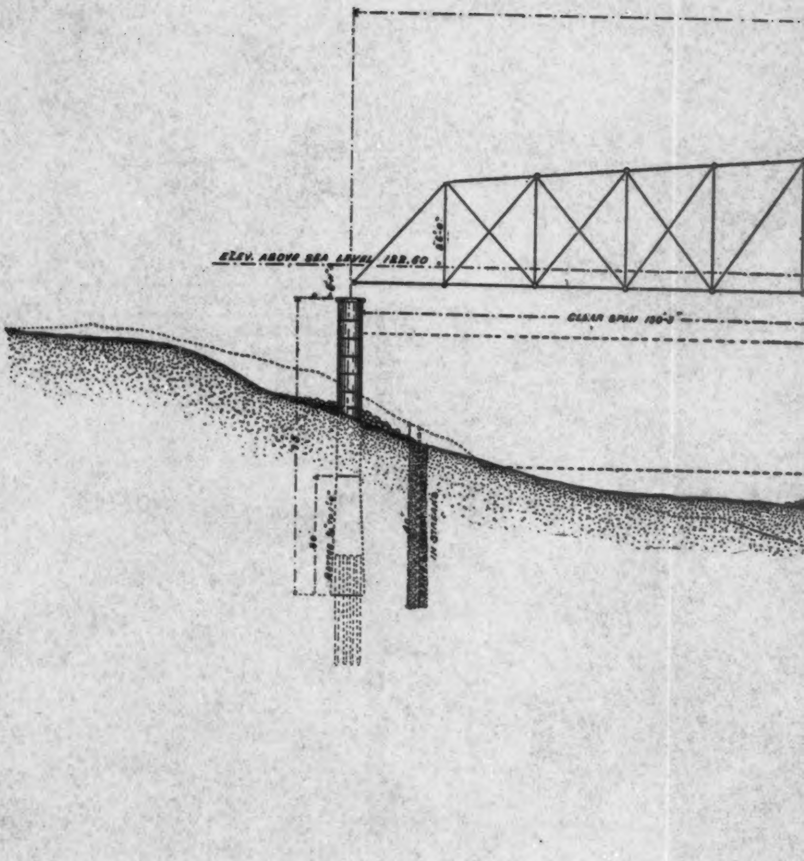
C. R. Grimm, M. Am. Soc. C. E. (by letter).—Mr. Wilson's statements certainly form some interesting items in the history of the work upon this tower, and I only wish to add that I had no knowledge, in

any shape or manner, of his design of an iron construction for the upper part of the tower until the day when I read my paper.

Mr. Hill must have undoubtedly misunderstood me when he thinks that an unreasonable architectural requirement interfered with the determination of the sizes of the members for the preservation of the form of the tower in plan. This subject is fully explained in the paper. Concerning his remarks with respect to the shell, I will confine myself to the remark—since the design of this shell has been outside of my province—that the bottom sections are not bolted to the top of the stone tower, and that the louvres are independent of the shell.

I regret very much that I am not in a position to satisfactorily answer Mr. McDonald, who points out that the paper does not give how closely the calculated stresses come to the elastic limit of the material. Without regard to a few specimens of square rods which were tested, no tests have been made in order to obtain knowledge of the qualities of the material, for reasons entirely unknown to me. On the other hand, the manufacturer was requested to furnish a material in compliance with the standard specification of bridge-builders.

In answer to Mr. Flagg's question, I must state that it is necessary to first coat the surface of the cast iron with copper, because if aluminum is deposited on any kind of iron, such an extremely thin and porous coat is produced that it would never answer the purpose for which it is put on in the present case.


ELEV. ABOVE SEA LEVEL 122.60
CLEAR SPAN

TR

KELLEY ON

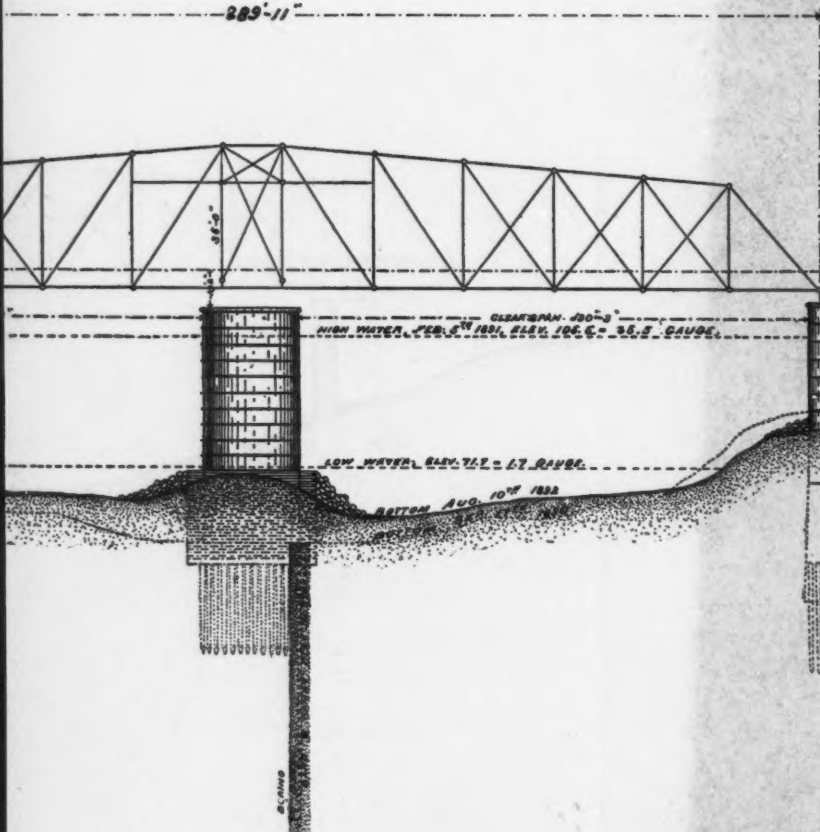
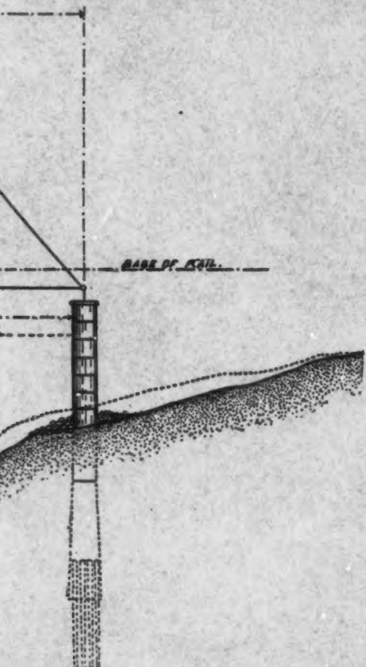

289'-11"
36'-9"
CLEAR SPAN 130'-3"
HIGH WATER FEB. 5TH 1891, ELEV. 106.C = 35.5 GAUGE.
LOW WATER ELEV. 71.7 = 1.7 GAUGE.
BOTTOM AUG. 10TH 1892
BORING

PLATE XXXV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXI, No. 695.
KELLEY ON RECONSTRUCTION OF PIVOT PIER.



AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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695.

(Vol. XXXI.—March, 1894.)

THE REMOVAL OF A DEFECTIVE PIVOT PIER, AND ITS RECONSTRUCTION.

By HOWARD G. KELLEY, M. Am. Soc. C. E.

READ DECEMBER 6TH, 1893.

On the afternoon of Saturday, September 13th, 1890, the St. Louis, Arkansas and Texas Railway draw span, with four panels of trestle approach, crossing the Ouachita River, at Camden, Ark., was wrecked, a 60-ton Mogul engine and nine loaded freight cars falling into the river with the collapsed structure. Fortunately, no one was injured.

The span destroyed was a combination Howe truss draw of 290 ft., total span, with curved iron top chord and iron bottom chord, erected in 1883, the road at that time being narrow gauge; all the wooden web members and the floor timbers had been renewed two years previous to the accident. The span rested upon a pivot pier composed of a cluster of cylinders; the central cylinder was 6 ft. in diameter, surrounded by six cylinders, each 4 ft. in diameter, all of the cylinders being braced together. The end rest piers were ordinary framed bridge seats on foundation piling.

By referring to Plate XXXV, it will be seen that the bed of the river was about 70 ft. below grade in its deepest portion, the bottom being

composed of sand, with 4 to 6-in. strata of sandy clay at intervals of about 10 ft. in depth.

Prompt measures were taken to remedy the disaster, and the next morning a force of company men was at work on the wreck. The broken span was pulled clear of the pivot pier down stream, the engine and cars rolled out of the way to make room for the erection of a temporary trestle, while another force was cutting from timber land a few miles distant the necessary long pine piling for this structure, the length of piling cut running from 70 to 85 ft. By night one track-driver commenced driving from the south end, and by the following afternoon a second track-driver commenced working from the north end, the latter driver having been brought from the Texas division and run over foreign lines to reach the work from the north side.

Five piles to the bent were driven, braced with 3 x 10-in. plank, the bents being spaced 14 ft. centers, cribbing being used over the pivot pier. The work was continued night and day, and by noon of Friday, the 19th, the trestle was completed and trains crossed the bridge, the regular train service of the road being continued without interruption until the final rebuilding of the new bridge.

The bridge having been originally erected under an act of Congress, specifying the length of clear span, application was made to the War Department for the privilege of reducing the length of span. Pending this decision the wrecking of the old span and rolling stock from the river was carried on, but it was not until the latter end of November that notice was received denying the application. A contract was immediately let to the Detroit Bridge and Iron Works for the superstructure, which was to be 290 ft. between centers of end pins, designed in conformity with Theo. Cooper's Specifications for Class A. The design was made by Mr. J. W. Schaub, M. Am. Soc. C. E., the engineer of the Detroit company.

An examination of the pivot pier showed extremely poor concrete, much of it being uncemented. The penetration of the cylinders in the sandy bed of the river varied from 14 to 16 ft., no piling having been driven in the bottom of them during the original founding. The pier was, therefore, condemned, and plans for its reconstruction considered.

To alter the location on the existing alignment of the bridge would have required a heavy increase in the length of the draw span, while

to have changed the alignment of the road to make a different crossing, up or down stream, would have required an expenditure of money which made it useless to take the plan into consideration. It now became apparent that the only feasible plan was the removal of the existing cylinder cluster and replacing it with a cylindrical pier.

The Ouachita is a turbulent river, subject to frequent extreme floods. The United States records show rises of 15 ft. in one night, but in the vicinity of Camden it is not subject to heavy scour or change of channel. It carries heavy drift in flood waters, with many large logs, and has sufficient current to cause logs to dive when striking an obstruction, making any plan for submerged pile foundations dangerous.

The contraction of the water-way, due to the trestle work and the wreckage, had produced some scour, making the depth in the middle of the river about 20 ft. below low water; therefore, the use of a pneumatic caisson, through which the old pier would necessarily be removed, was considered impracticable from both a constructive and financial point of view; but by the use of an open caisson, or coffer-dam, sunk to a sufficient depth below the bed of the river, the defective pier might be removed economically and a new one constructed within the walls of the caisson. The difficulty of handling such a caisson, and the gravity of the work under the surrounding conditions, were fully appreciated, but it was judged to be the only feasible method, and the plan was developed as follows:

"GENERAL PLAN OF THE WORK.

"*First.*—Sink a double-walled caisson or coffer-dam to a penetration of 10 ft. below the scoured bed of the river, the caisson to surround the cylinder cluster.

"*Second.*—Fill the interior space in the coffer-dam with piling, driven to as great a depth below the cutting edge as possible.

"*Third.*—Seal the interior with concrete, pump it out, cut off the piling and the six small cylinders below low water, capping them all with square timber, upon which a grillage of square timber should rest, said timber to surround and be fitted to the central cylinder, which, as stated before, was 6 ft. in diameter.

"*Fourth.*—Cut off the central cylinder about 2 ft. from the top of the coffer-dam.

"*Fifth.*—Upon the grillage erect a cylinder of riveted steel plates 24 ft. in diameter and 44 ft. high, filled with concrete, to be surmounted with a limestone coping 24 ins. thick."

Estimates were made upon this general outline of plan, and the plan submitted to contractors for bids, with the privilege of their submitting bids based upon plans of their own, if they so desired.

The reputation of the Ouachita River as being a treacherous and turbulent stream was well known among substructure contractors; therefore no surprise was felt when they declined to bid upon plans of their own. But when the lowest bid based upon the plan outlined above was received, and found to exceed by 40% the estimate made for the actual cost, some explanation to the management of the Company appeared to be in order.

The subject was then carefully considered by the General Manager, Mr. W. B. Doddridge, and the writer, feeling confident that the work could be done in the manner and for the amount of money he had specified, was authorized to proceed with the work with the regular Company forces. The work was completed precisely in accordance with the prepared plans and specifications, including the cleaning up and shipping to headquarters of all machinery and surplus material, at a total cost of 85% of the original estimate, and $60\frac{7}{10}\%$ of the lowest bid received.

History and Description of the Work.

Active work was commenced on December 18th, cleaning up all remaining portions of the wrecked bridge, and, by means of a submarine diver, fastening chains to the engine, which had not up to that time been secured. A submarine diver was employed by the month, the Company furnishing the diving outfit. Especial care was taken to remove every obstruction, such as drift and old logs, from around the pivot pier within the area of the proposed coffer-dam, the diver using a strong water-jet to assist him in this work.

To protect the coffer-dam from the pressure of the current, a breakwater was driven about 175 ft. up stream in V shape, with the wings projecting down stream and flaring out slightly beyond the sides of the coffer-dam (see Plate XXXVI). Each wing consisted of a line of fourteen pine piles braced with two battered piles at its down-stream end, to better resist fields of drift; the wings were capped with a 12 x 12-in.

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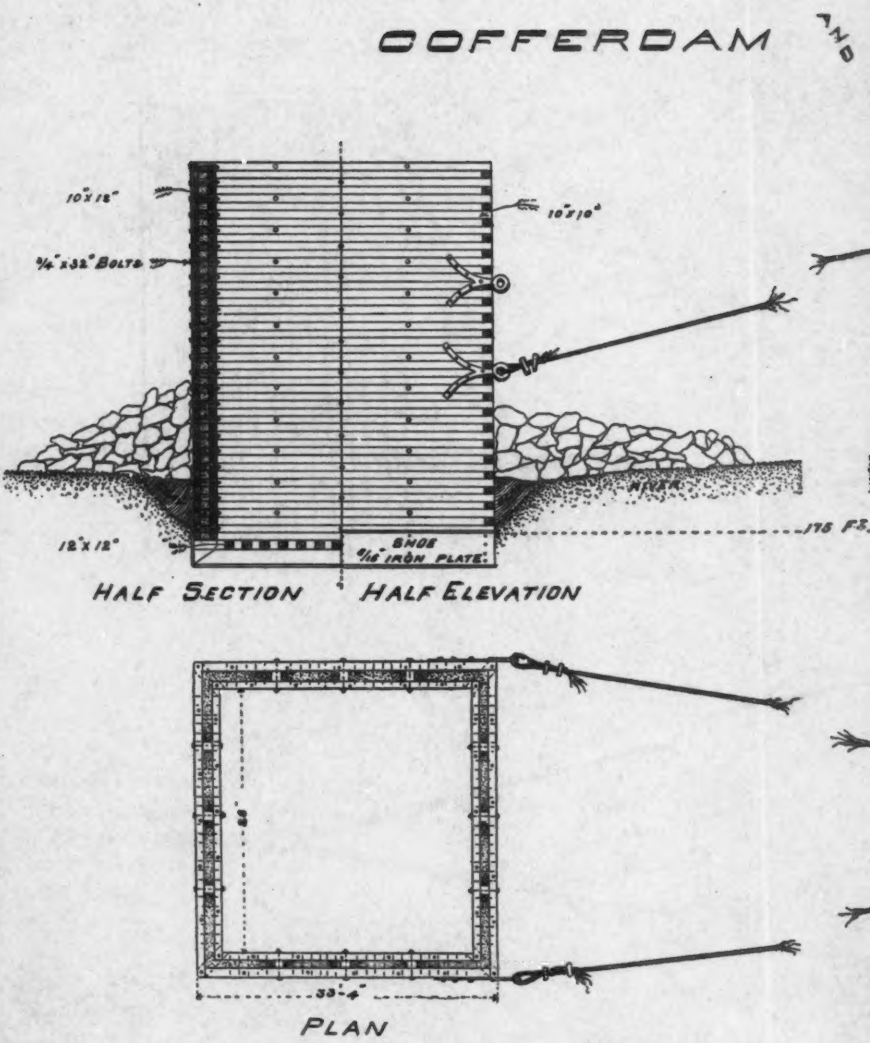


KELL

AND BREAKWATER

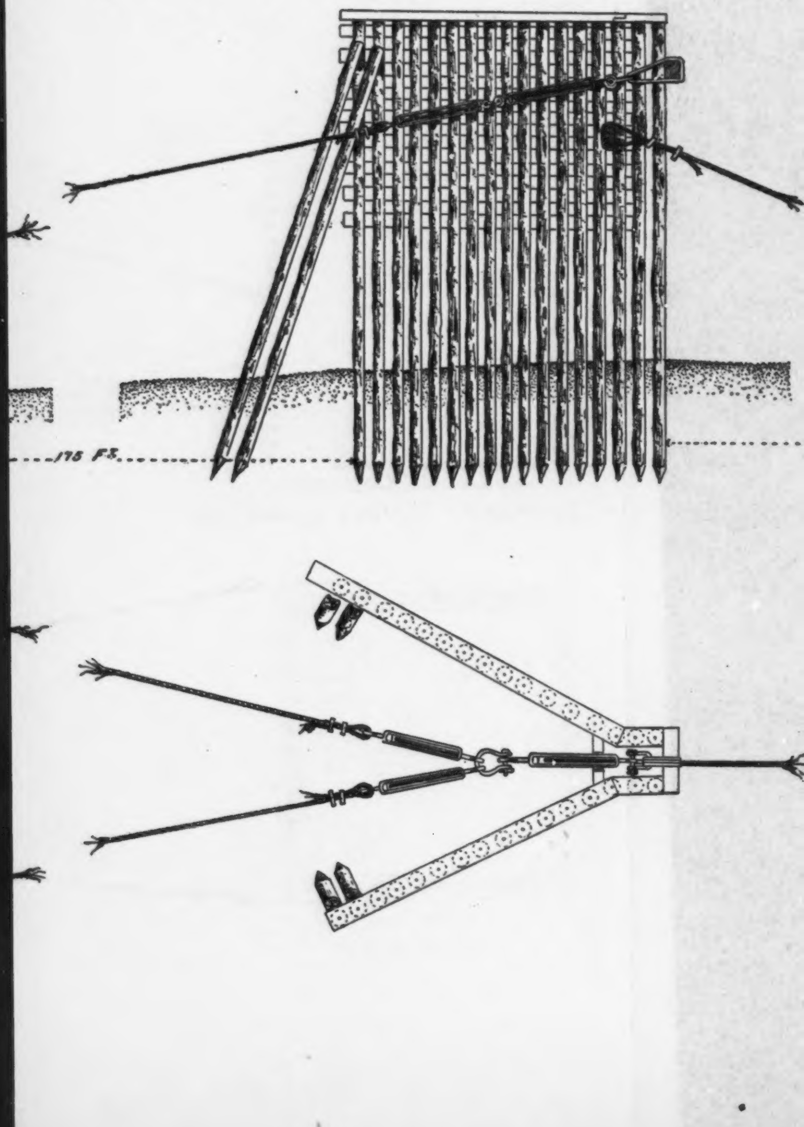
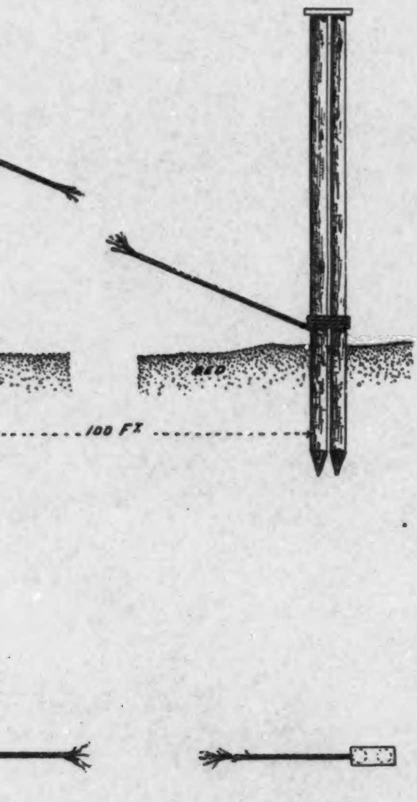


PLATE XXXVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXI, No. 695.
KELLEY ON RECONSTRUCTION OF PIVOT PIER.



timber 36 ft. long, and slatted up on the up-stream side with rows of 2 x 8-in. plank. The nose of the breakwater consisted of four heavy pine piles capped with 12 x 12-in. timber, on which a platform was built.

About 100 ft. up stream from the nose of the breakwater two pine piles were driven and chained together ; a wire rope made into a sling at one end was passed around these piles, the sling allowing the line to settle to the bottom ; the other end was then carried to the nose of the breakwater and a strain put upon the line, which was then made fast, thus acting as a guy to stiffen the breakwater.

To assist in the river work, two decked barges had been built, dimensions 12 ft. x 32 ft. x 2 ft. deep, being made very strong and stiff; also, two open barges, 8 ft. x 16 ft. x 18 ins. deep ; also, some floating runways, which could be run from the shore to any part of the work desired.

It was presumed that the coffer-dam could be held in position laterally by bracing against the pivot pier when necessary, but to support it against the current wire cables 1¼ ins. in diameter were led from the different anchor-straps on the sides of the nose of the breakwater, as shown in Plate XXXVI, additional anchor-straps being added when necessary. By the aid of adjusting screws and a crab winch on the nose of the breakwater, sufficient strain could be put on the cables to hold the coffer-dam in position up and down stream and twist it as occasion might require. This plan worked admirably throughout the sinking.

Some additional work was also necessary on the temporary trestle to make room for the coffer-dam, and a clear channel span of 24 ft. was required to permit rafts to pass through, the track being carried by some trussed stringers.

The trestle was also stiffened to resist floods and accumulations of drift, by running six wire cables 1¼ ins. in diameter each from it up stream to trees on the bank, where the cables were made fast.

On February 14th, everything having been prepared, and the engine and wreckage taken out of the river, the iron shoes forming the cutting edge of the coffer-dam were floated out to the pivot pier on the barges, the shoe being in four sections; it was assembled in place around the pier and riveted together, and the first four courses of wall built upon it. Its weight was supported by the barges and eight crab winches stationed on the platform built in the trestle overhead.

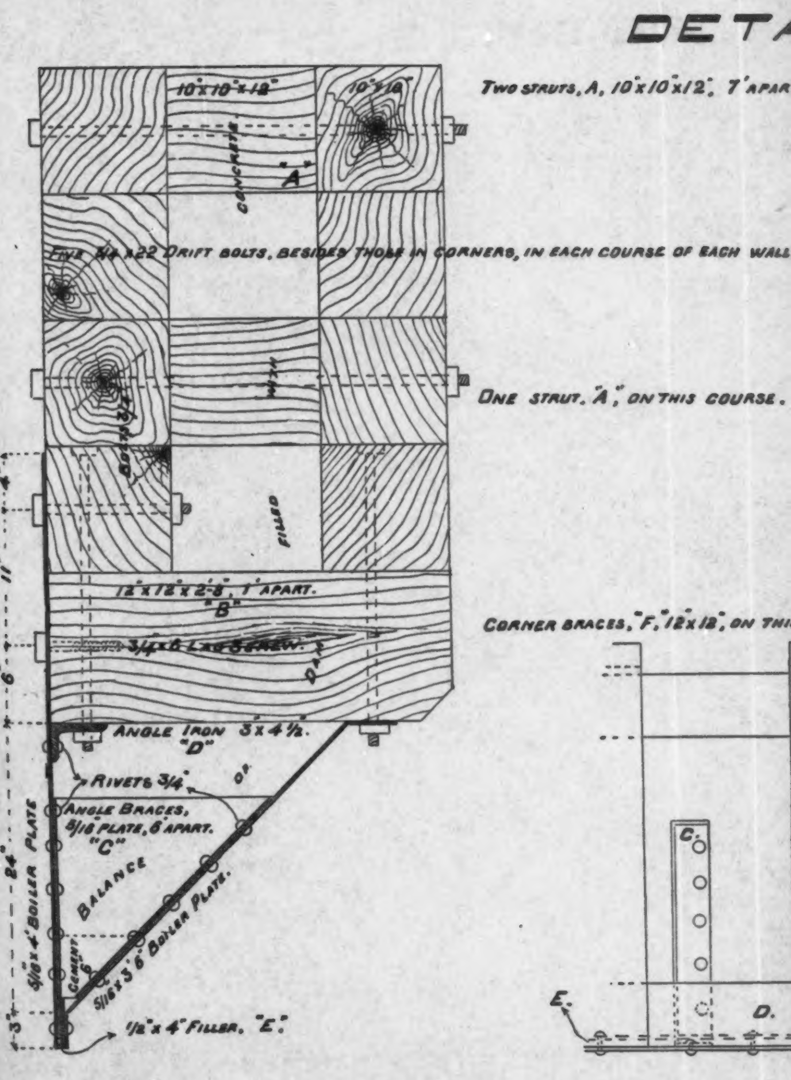
The shoe was then filled with concrete, and on February 18th it was lifted clear of the barges by means of the crab winches, then lowered into the water until all but the top course of timbers was submerged; on this date the gauge read 20.3 ft. above low water, which gave a total depth at the pivot pier of about 39 ft.

By referring to Plates XXXVI and XXXVII, the construction of the coffer-dam can be seen. In plan it was 28 ft. square in the clear inside, and 33 ft. 4 ins. outside; the double walls were of 10 x 10-in. timbers, ordered 32 ft. and 34 ft. long, so that no splicing would be necessary in the walls. Each course of timbers was drift-bolted to the course below with five round iron drift-bolts, $\frac{3}{4}$ x 22 ins. each side, besides the bolts in the corners. The coursing timbers were not halved or framed together, but were simply cut square and fitted in place with alternate butt and lap joints.

At every alternate course strut blocks were placed between the double walls; these blocks were of 10 x 10-in. timber, 12 ins. long, which was the clear space of the double wall. A $\frac{3}{4}$-in. hole was then bored through both walls and the block and the timber drawn together by an iron bolt $\frac{3}{4}$ x 32 ins. long. This system was carried around all four sides of the coffer-dam and continued to the top course.

The iron shoe was of $\frac{5}{16}$-in. plate iron, made in a V-shaped trough section with the line of the outside plate vertical, and in line with the outside wall of the coffer-dam (see Plate XXXVII); they were stiffened and riveted together with plates and angles. On top of this shoe rested, first, a series of foundation blocks 12 x 12 ins. x 2 ft. 8 ins., placed 12 ins. apart in the clear, and mitered at the corners of the coffer-dam, each block being bolted to the shoe as shown. On these blocks rested the double walls, the first course being bolted down with the same bolts by which the foundation blocks were bolted to the shoe.

The shoe was then filled with concrete up to the top of the foundation blocks. Tackle had already been fastened to all four corners of the coffer-dam and to the centers of each side wall. This tackle was suspended from the ends of trussed beams placed across the top of the track circle of the old pivot pier, the truss rods leading up and over the stringers of the temporary trestle; the hauling lines led through snatch blocks to the eight crab winches before mentioned. Everything being in readiness, the winches were manned and a steady strain put upon all eight lines, lifting the constructed portion of the coffer-dam


DETA
Two struts, A, 10"x10"x12". 7' apar
10"x10"x12"
10"x10"
Concrete
"A"
Five 3/4 x22 Drift bolts, besides those in corners, in each course of each wall
One strut. "A", on this course.
Filled
12"x12"x2'-8", 1' apart.
"B"
Corner braces, "F," 12"x12", on thi
3/4x6 Lag Screw.
Angle Iron 3"x4 1/2.
"D"
Rivets 3/4"
Angle Braces,
5/16" plate, 6" apart.
"C"
Balance
5/16"x3'6" Boiler Plate.
5/16"x4' Boiler Plate
Cement
1/2"x4" Filler. "E."
4"
11"
6"
24"
3"
C.
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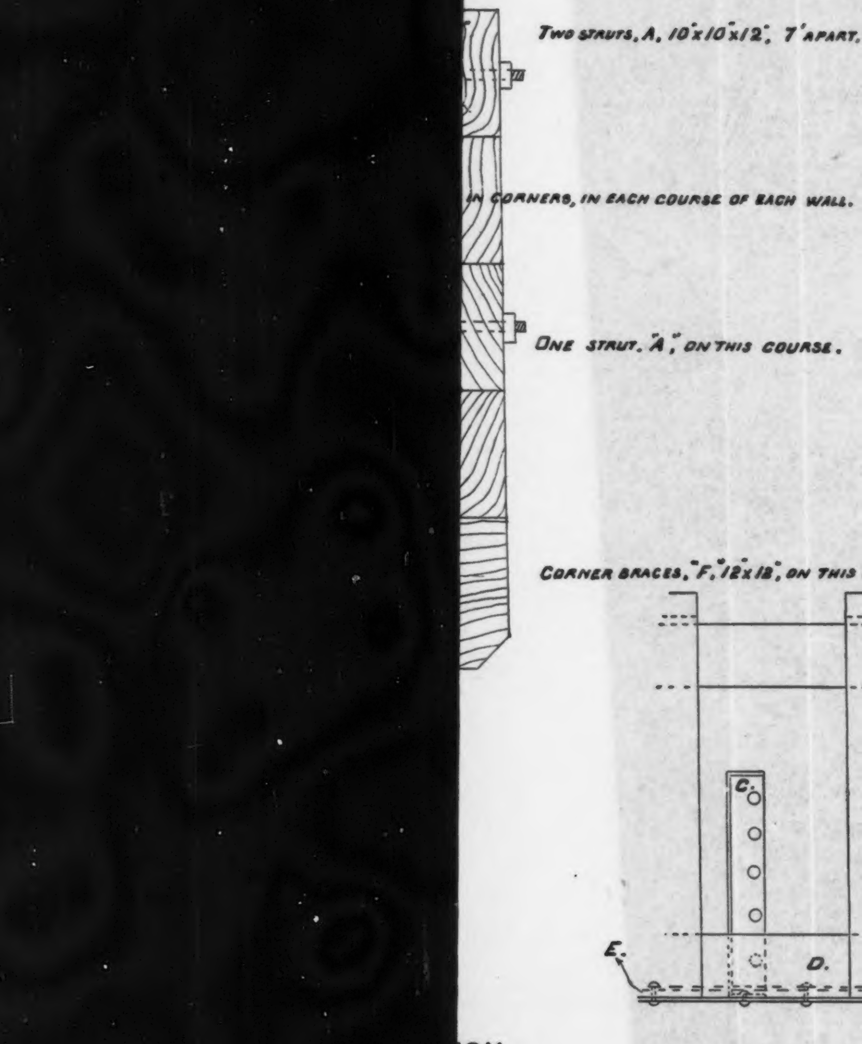
E.
SECTION

DETA


Two struts, A, 10"x10"x12", 7' apart.
in corners, in each course of each wall.
One strut, "A", on this course.
Corner braces, "F," 12"x12", on this
C.
D.
E.

ON

PLATE XXXVII.
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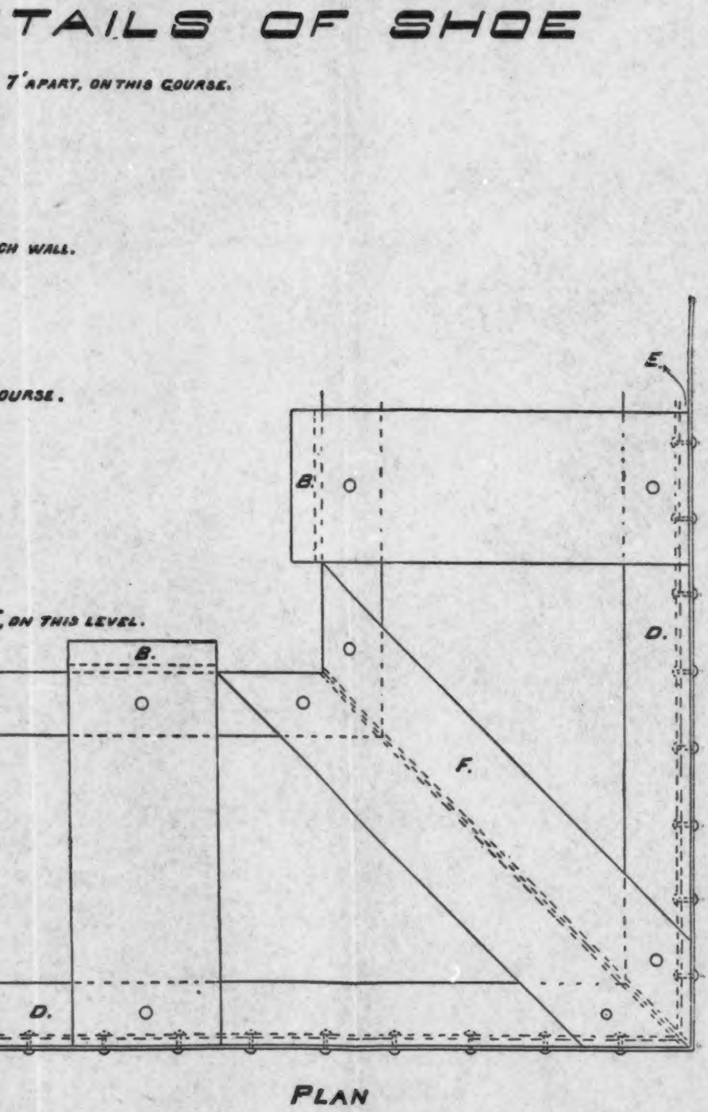


up slowly from the barges, which were then hauled out of the way. The coffer-dam was then lowered until only the top course of timbers remained out of the water. The total estimated weight thus lifted was 99 200 lbs.

The construction was carried on by bolting the wall timbers in place and lowering away on the tackle until the buoyancy of the timbers somewhat relieved the tension, when more concrete was added in the space between the walls until the weight was sufficient to keep a constant strain on the tackle, experience confirming the original opinion that it would be more manageable when heavy than when partially buoyant.

This concrete was mixed on one of the small barges alongside and was deposited in place through a box chute 10 ins. square, the leakage of water through the double walls when first made being sufficient to keep the 12-in. wall space nearly full of water.

Meanwhile a force of men was employed preparing for the later portions of the work; the steel cylinder material had been ordered, and was being constructed and inspected at the shops; concrete rock was being received by train and unloaded at a convenient place on the river bank; the platform and shed for mixing concrete were erected, and all necessary provision and details for the economical and successful prosecution of the work were given due attention. One of the most successful features of the work was that no portion of it was ever held or delayed for want of necessary material or preparation beforehand.

On March 4th the coffer-dam landed on the bottom of the river, 44 courses of timber wall having been built on top of the shoe, giving a total height of 40 ft. 8 ins., the gauge reading 20.3 ft. The wall space was then filled to the top with concrete. The coffer-dam was then carefully set in position by means of the guy lines. A transit was used to determine the true position, and to set reference points on the temporary trestle, by which the position of the top of the wall could be determined at any time.

The plan designed for the sinking was for a diver to use a strong jet of water delivered through a nozzle in a 2-in. rubber steam hose. The diver worked inside the coffer-dam, jetting the material away from the cutting edge and toward the four corners of the coffer-dam. By reference to Plate XXXIX it will be seen that vacant spaces existed at these points between the walls of the coffer-dam and the small cylinders, these spaces being sufficient to permit the use of a Hayward dredge.

A system of four derricks had been erected on the trestle work overhead, as shown in Plate XXXVIII, and a hoisting engine set up, by which the dredge could be handled in all parts of the coffer-dam and could be passed from one derrick to another over the coffer-dam and beneath the decking of the trestle, without landing it.

There was but little rip-rap found around the pier, and this was removed by means of the dredge, the larger pieces being loaded into the dredge by hand by the diver.

The weight of the coffer-dam now enabled it to be handled in a manner somewhat similar to a pneumatic caisson, for by means of the jet the cutting edge could be thrown up or down stream, or across, as occasion demanded, while at the same time the guy lines held it in whatever position was required above.

The timber walls were continued up as the coffer-dam penetrated the bottom, until it reached a total height of 48 ft., or 52 ft. above the cutting edge. It was not deemed expedient to build it any higher, but the fluctuating floods were allowed to submerge it, this submersion occurring twice during the sinking without any harm resulting other than the delay to the work, while the coffer-dam was submerged.

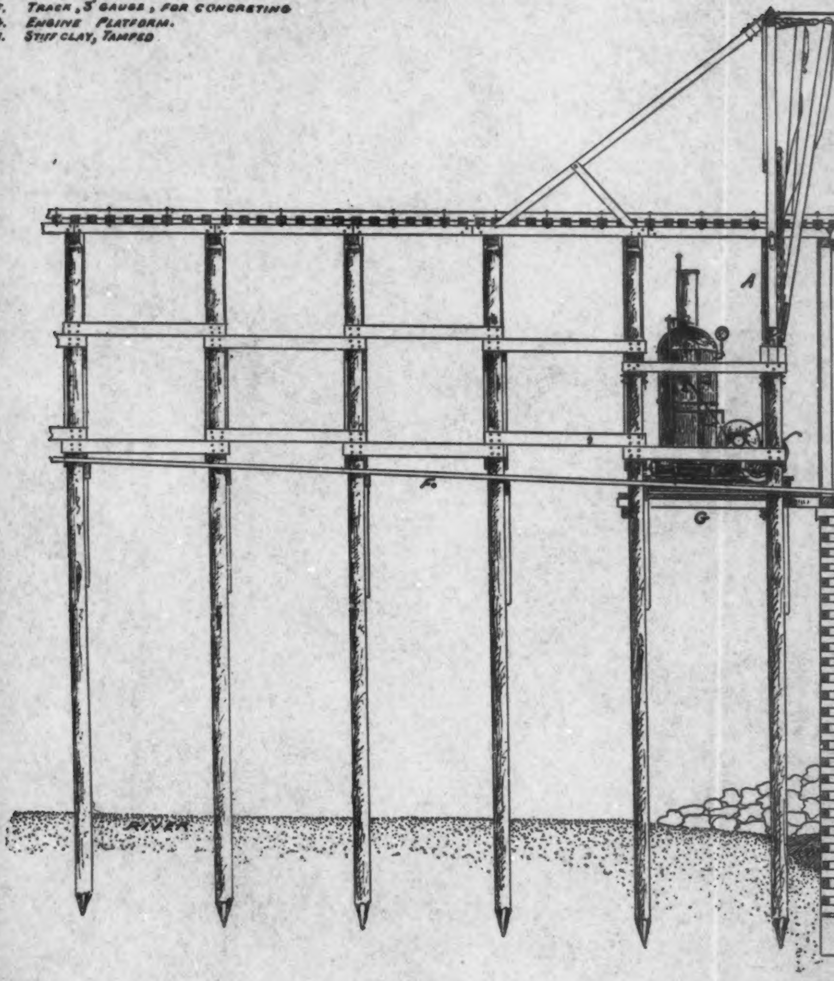
The following is a condensed table of gauge records, showing the highest and lowest points of fluctuation during each month, with the dates :

GAUGE RECORD.

DATE.	ELEVATION ABOVE LOW WATER.	
	Highest.	Lowest.
December 20, 1890	....	6.2
" 29, "	19.0	
January 1, 1891	....	14.3
" 14, "	31.3	
" 26, "	....	12.3
February 5, "	35.4	
" 16, "	....	19.1
" 26, "	32.2	
March 6, "	....	17.1
" 12, "	32.0	
" 31, "	....	19.1
April 3, "	21.9	
" 16, "	....	12.3
" 26, "	29.8	
May 14, "	....	7.1
" 21, "	16.0	
" 31, "	....	7.5
June 9, "	....	4.6
" 20, "	9.4	
July 1, "	....	5.0
" 8, "	9.0	
" 27, "	....	3.8

REFERENCE:

AA. DERRICKS, 19' FROM TOP OF RAIL TO BOTTOM OF CROSS-BEAM.
B. COFFER-DAM, 48 COURSES OF 10x10=40'+4' SHOE=44' TOTAL HIGHT.
C. TRUSS & EXTRA BENTS, AFTER REMOVAL OF OLD CYLINDERS.
D. "CHANNEL" TRUSS, 24'.
E. PILE-DRIVER, LEADS 22", 34' LONG
F. TRACK, 3' GAUGE, FOR CONCRETING
G. ENGINE PLATFORM.
H. STIFF CLAY, TAMPED



TRESTLE AND DERRICKS

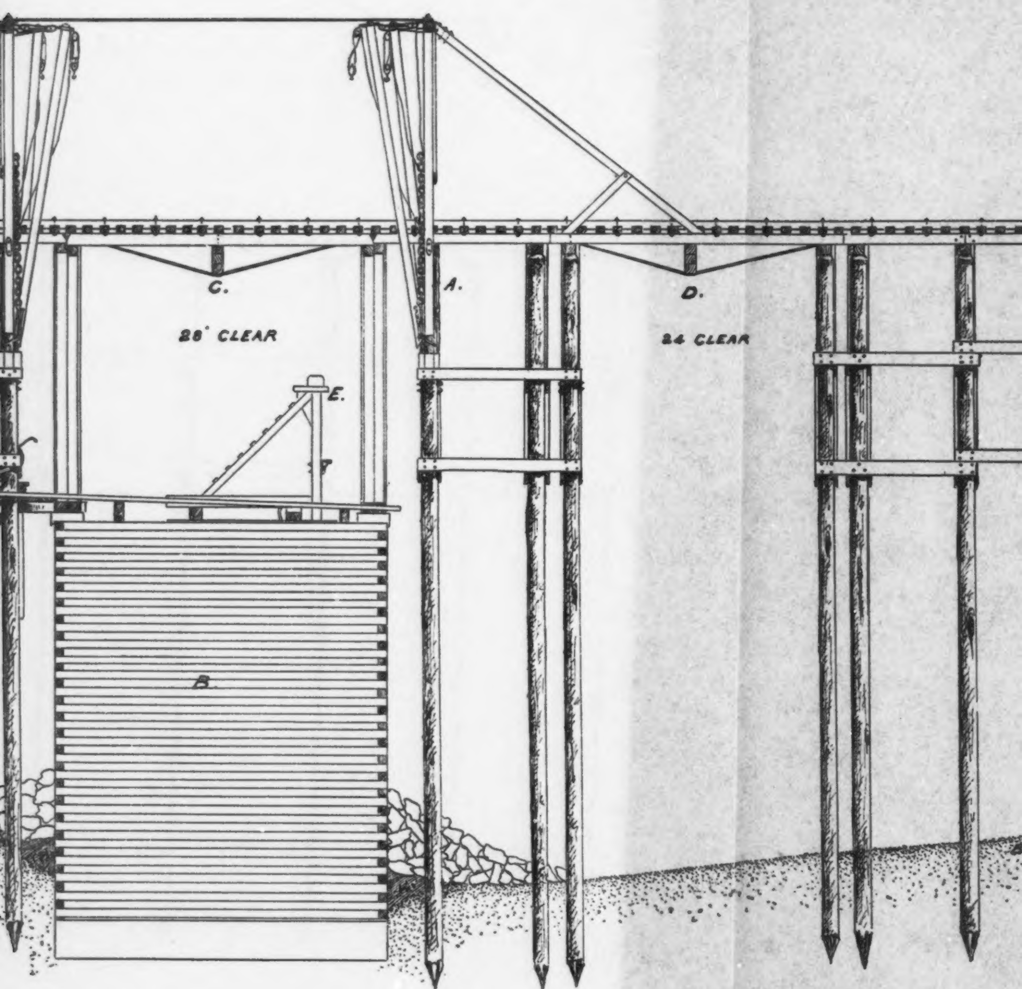
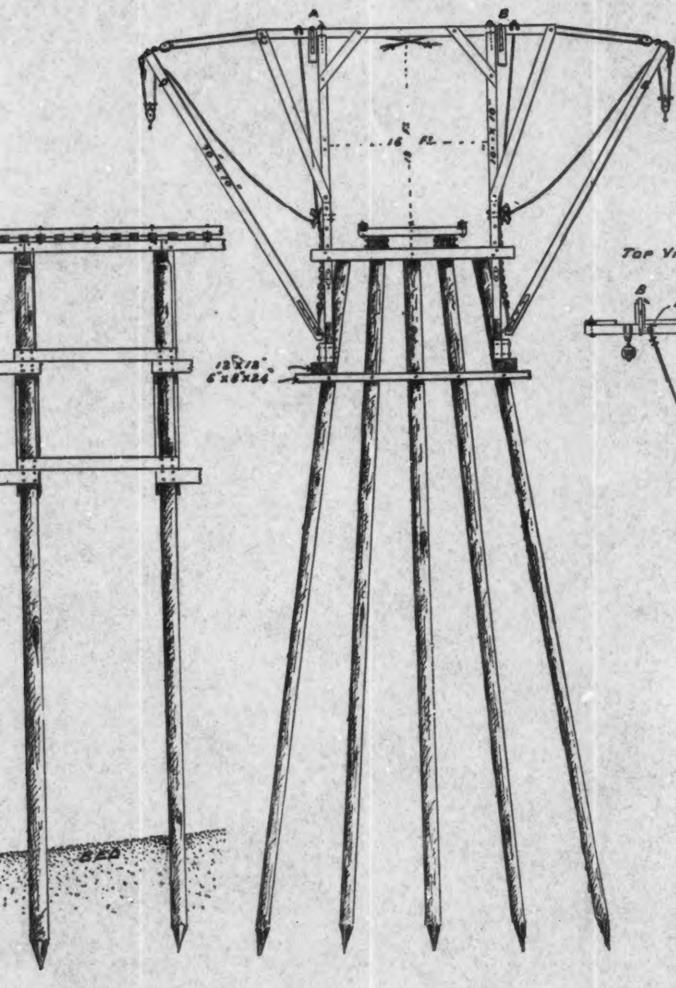
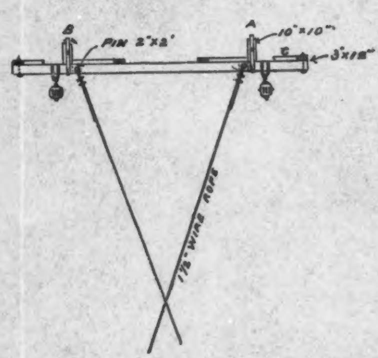


PLATE XXXVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXI, No. 695.
KELLEY ON RECONSTRUCTION OF PIVOT PIER.



TOP VIEW OF CROSS-BEAM.



This table shows a record of four successive floods higher than 30 ft. above low water, making a total head of water to work against of over 50 ft. At a gauge of 30 ft. the water would overflow the high south bank where the work and material yard was located, compelling the boarding outfit to pull out to higher ground at Camden station, about one mile away, and stopping all work except such as could be done from the trestle or the barges in the river.

During the sinking a ditch about 4 ft. deep formed around the outside of the walls of the coffer-dam. This was expected, but on the upstream right-hand corner some scour commenced, cutting a trench through the coffer-dam diagonally across to the middle of the downstream wall. This might have proved serious, but was successfully stopped with sandbags deposited in the ditch outside, and also by keeping that corner of the coffer-dam hard down by extra weighting it with sandbags laid on top of the wall, the broad walls of the coffer-dam affording an excellent gangway for the men to work upon.

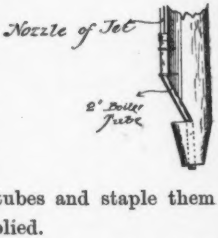
On April 4th, the cutting edge had reached an average penetration of 10 ft. below the river-bed, having been landed within 2 ins. of parallel with the axis of the bridge, the center being $1\frac{1}{2}$ ins. down stream and 1 in. further north than the mathematically true position. Gunny sacks, partly filled with concrete, were then placed by the diver inside and underneath the overhang of the shoe, filling the space entirely, as shown in Plate XXXIX. A row of sacks were then laid in the ditch outside and against the walls, after which the ditch was filled with stiff clay, on top of which rip-rap was placed. As the clay was deposited, it was tamped in a simple and satisfactory manner by having the diver walk around the dam, forcing the clay hard into place with his iron shoes. The diver being an old experienced man, it was not necessary to pump sufficient air into the dress to make him buoyant when on the bottom while the protection afforded by the breakwater prevented the river current sweeping him off his feet.

The cribbing was now removed from over the old pivot pier; framed bents were erected on the walls of the coffer-dam, and some trussed stringers, with 29 ft. clear span, substituted to carry the track, each chord of this truss being composed of three pine stringers of 8 x 16 in. x 31-ft. dimensions, trussed with two iron rods, 2 ins. square (see Plate XXXVIII), the coffer-dam showing no settlement whatever when the weight of the trains came upon it.

The entire cluster of cylinders was then cut down to about 2 ft. below the top of the coffer-dam; a pile-driver was set up over the coffer-dam, supported by trussed beams resting on the walls, the Lidgerwood pile-driver engine having been previously placed on the platform in the trestle, clear of the coffer-dam, in such a position that it could, with the aid of snatch-blocks, handle the four derricks as well as the pile-driver.

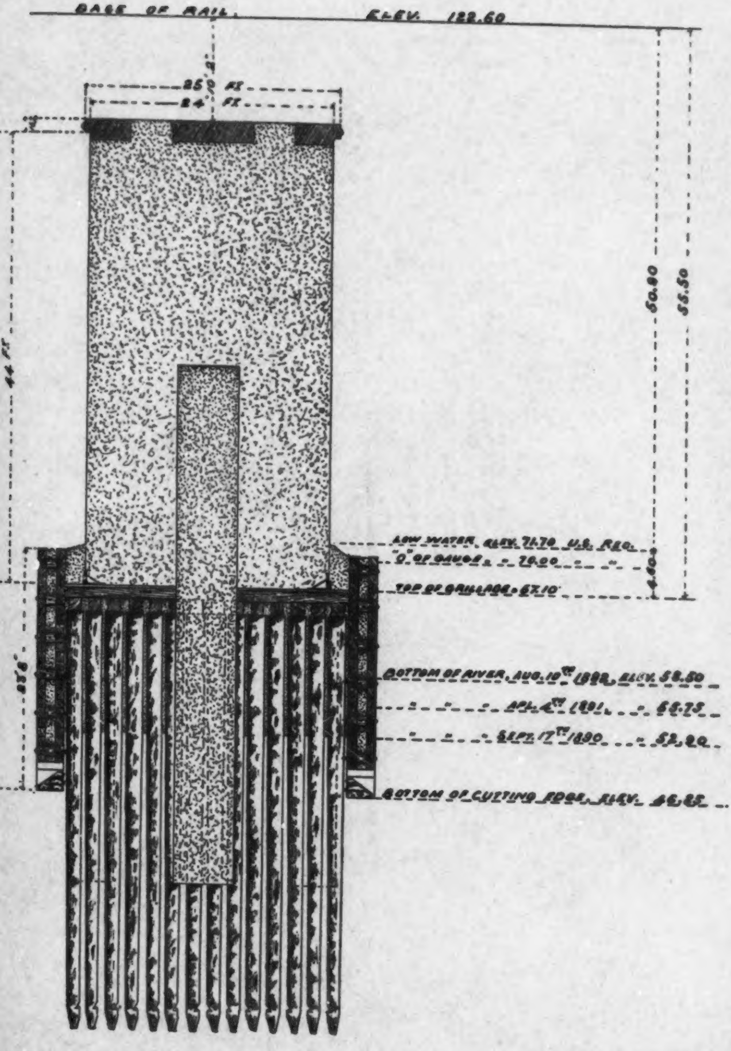
The pile-driver leads were 22 ins. apart in the clear, carrying a 3 000-lb. hammer. The piles used were of red cypress, 55 ft. long, with not less than 10 ins. of heart at the small end, and were driven with the assistance of a jet. The weight of the pile and hammer carried the piles down from 10 to 15 ft., while the jet was at full blast. The hammer was then used to strike, being raised only from 2 to 4 ft. at each blow, until a total penetration of 23 to 24 ft. was obtained below the cutting edge of the coffer-dam. The jet was then withdrawn, and a few blows, with a fall of 12 to 15 ft. were given, the piling all refusing to move under the last few blows.

The method of using the jet is shown below. It worked perfectly, the piles penetrating vertically, and in only two cases did they shoot out to one side, the workmen humorously terming them "flageolet piles." The tubes were old worn-out engine boiler tubes, taken from the scrap pile; the nozzle of the jet was 1½ ins. gas pipe, attached to 2 ins. jet hose, and of sufficient length to reach the working platform, where it was handled by one man, and raised when the pile was driven by means of a small line run through a snatch-block, and thence to one of the spools on the engine. The workman simply held the jet pipe firmly against the pile, and kept it pressed down inside the boiler tube, as shown on the accompanying drawing, while the pile was being driven.



The piling having been previously skidded up alongside the track when unloaded from cars, two men with an axe and an augur were able to trim and notch the piles, insert the tubes and staple them to the piles fast enough to keep the driver supplied.

The work of driving commenced on May 29th, and was completed on June 13th. Two piles were the least number driven in any one day, and nine piles the greatest number; 87 piles were driven



SECTIONAL ELEVATION

PLATE XXXIX.
TRANS. AM. SOC. CIV. ENGRS.
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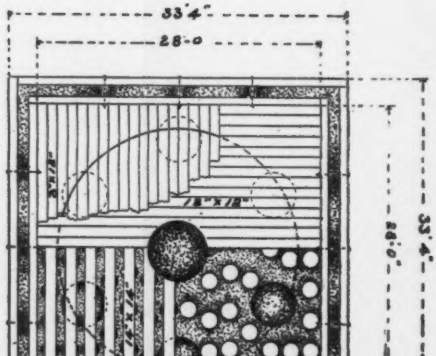
KELLEY ON RECONSTRUCTION OF PIVOT PIER.

PIVOT PIER



PLAN

COPING

in all, or an average of $5\frac{44}{100}$ piles per day. The sand displaced by the driving rose to a height of 6 or 7 ft. above the cutting edge inside the coffer-dam.

The piles were then blocked into position for the grillage caps, after which a layer of Portland cement concrete 2 ft. thick was deposited around the piling. Over this Louisville cement concrete was placed to within 1 ft. of the proper height of the cut-off for the piles and the mass allowed to set for 24 hours.

A No. 5 Nye steam vacuum pump was then suspended in one corner of the coffer-dam, and on June 29th was set to work, pumping the coffer-dam dry in two hours. One or two small leaks developed through defective sealing in the corners of the bottom, while in the joints of the wall the leakage was not appreciable, most of the leaks being stopped by driving shingles in the joints; the total leakage did not amount to over 100 galls. per hour, an amount much less than had been anticipated.

No braces across the dam between the walls were necessary, for the walls actually stood a height of water of $16\frac{1}{2}$ ft. outside, without any bulging being detected.

The piling was now cut off ready for the grillage, the small cylinders 4 ft. in diameter were taken down to the same level, the concrete removed from them being thrown overboard for rip-rap; the entire bottom was then leveled off with good concrete even with the cut-off of the piles and the small cylinders.

The grillage consisted of a series of fourteen pine caps, 14 x 14 ins. x 28 ft., laid on the rows of piling and small cylinders, the center rows being cut to fit against the central cylinder which, it will be remembered, had not been cut down, but still projected up to within 2 ft. of the top of the coffer-dam. These caps were laid up and down stream and drift-bolted with round iron drift-bolts $\frac{7}{8} \times 22$ ins. Concrete was then filled in between these caps flush with their tops; cross-caps of pine 12×12 ins. $\times$ 28 ft. were then laid down on this, fitted to the central cylinder as before and drift-bolted to the lower caps. Upon this was laid a floor of 3×10-in. pine plank, laid up and down stream, and spiked with 8-in. boat spikes. The circumference of the 24-ft. cylinder shaft was then marked out on the floor, and the periphery of this circle brought to a perfect surface with the foot-adze; wrought-iron shoe braces were then bolted to the floor on the inner

circumference, to form a perfect circle for the bottom course of the cylinder shell.

This cylinder, as before stated, was 24 ft. in diameter, built of $\frac{5}{16}$-in. steel plate, 44 ft. high, in sections of 4 ft. in height.

When it was determined not to build the coffer-dam higher than 20 ft. on the gauge with the full penetration reached, it was decided to make the cylinder shell water-tight, so that concreting could be carried on inside it in the open air if the dam itself were submerged. The segments of each course were therefore made with planed horizontal butt joints and butt strips, the vertical joints of each segment breaking joints with those of the section below.

The bids for the cylinder material were based upon the following specifications, but the best bid received, calling for $\frac{5}{16}$-in. steel with a higher tensile strength, it was accepted and the steel cylinder used:

"SPECIFICATIONS FOR THE IRON CYLINDER SHELL FOR THE PIVOT PIER AT OUACHITA RIVER.

"The pivot pier shall consist of a wrought-iron riveted shell made of a good quality of plate iron $\frac{3}{8}$ in. in thickness, and 24 ft. inside diameter, and, when riveted up, shall be a total height of 44 ft.

"Each horizontal section of the shell shall be made of plates 4 ft. in width, and of such length that there may be twelve sheets of equal length in each horizontal section; they shall be butt-jointed in both horizontal and vertical joints, and riveted together with butt or packing strips on both vertical and horizontal joints, the packing strips to be of $\frac{3}{8}$-in. iron, 6 ins. wide.

"The horizontal strips shall be riveted on the outside of the horizontal joints; they shall be riveted in the shop to the upper edge of the sections; the vertical strips shall be riveted on the inside of the vertical joints, and shall project 3 ins. both above and below the plate, and shall be pierced with rivet holes on these extensions, so they may be riveted to the sections both above and below.

"All work to be single riveted with rivets $\frac{3}{4}$ in. in diameter and 3-in. pitch.

"All joints to be close and neatly fitted together, the horizontal joints to be planed to a true bearing so the cylinder may be caulked with a caulking tool after the sections are assembled together.

"To admit of easy handling, the sections must be shipped in third-circle segments one plate wide, and, to insure a close fit of the rivet holes for the field riveting, an inspector will be sent to the shops while the cylinder is being made and each horizontal section complete fitted

to the one above and below, and the rivet holes which are to be riveted in the field shall be reamed out to a perfect match; each segment must then be marked plainly with its exact position in the cylinder, so there may be no confusion of parts while the work is being assembled in the field.

"All riveting and shop work must be done in a thoroughly workmanlike manner, subject to the inspection and approval of the inspector.

"The iron used in the shell shall be capable of being bent cold to an angle of 180°, and to a curve whose diameter equals three times the thickness of the plate without showing signs of fracture, and shall develop a tensile strength, when tested in specimens of a uniform sectional area, of at least ½ sq. in. for a distance of 10 ins., of not less than 46 000 lbs. per square inch.

"The top and bottom section shall be reinforced on their top and bottom edges, respectively, with a regular 6-in. packing strip to secure greater stiffness.

"Enough rivets shall be furnished of the proper size by the contractor to complete the field riveting, allowing an excess of 10% over the actual number required.

"All segments shall be painted on both sides with one coat of good red iron ore paint, the quality of the paint to be subject to the approval of the inspector.

"Should it be found necessary, before the cylinder is completed and shipped from the shops, to add another 4-ft. ring or a fractional part in height thereof, it shall be furnished by the contractor in full conformity with the above specifications and at the same price per pound.

"Time being an essential object, the contractor will be obliged to state the time of delivery; all bids to be based on a price per pound f. o. b. Cairo, Ills."

The amount of shop work specified might be considered excessive, but as skilled labor of that class was difficult to obtain in this locality, it was thought advisable to secure accuracy in the shop; and the price per pound obtained was not in excess of the average price for ordinary cylinder material.

As fast as the cylinder segments were riveted in place, the interior was filled with concrete well rammed, the central 6-ft. cylinder being allowed to stand as it was and be entirely buried in concrete. The concrete for the cylinder shaft was made of the best English Portland cement with sand and broken stone, in the proportion of 1 part of cement, 3 parts of sand and 6 parts of broken stone, all measured by volume. It was mixed on a platform on the river bank in the usual

manner with hoes and shovels. From this platform an inclined track was built out on the side of the trestle, with a descending grade to the top of the coffer-dam. A push car carried a dump-box, which contained 1 cu. yd. of concrete, from the mixing platform to the coffer-dam, where the box was picked up by the derricks and dumped in any part of the cylinder required. The grade of the push-car track was such that when it was at the mixing platform, the top of the dump-box was level with the floor of the platform, so that nothing required to be lifted by hand.

On July 13th the first ring of the cylinder was riveted in position, and on August 28th the work was completed ready for the coping, some delay occurring, owing to the necessity of diverting the force to prepare the false work for the superstructure.

The design for the coping can be seen in Plate XXXIX. It consisted of a circular center 8 ft. in diameter, and a series of circumference or ring stones, the space between these ring stones and the center being filled with concrete well rammed to within 2 ins. of the surface of the coping, when the balance was filled up level and smoothed off with a mortar composed of Portland cement, sand and the screenings of the broken stone used for concrete, in about equal proportions. This made a very firm coping, and the concrete filling was hardly distinguishable from the cut stone, except for the absence of mortar-joints.

The coffer-dam having served its purpose, it was then torn down, coming apart quite readily with the aid of steel wedges and timber grab-hooks attached to the derrick falls.

The intention was to tear the walls down to within one or two courses of the top of the grillage, but, during the writer's absence, the foreman, mistaking his instructions, left four courses standing and filled the space between the walls and the cylinder with concrete, as shown in Plate XXXIX. This was allowed to remain, as it would have been an unnecessary expenditure of time and money to remove it.

The coffer-dam being a strong and permanent structure, that portion of it left surrounding the piling and penetrating the river bottom was a permanent and effective protection to the piling against scour and sinking drift, and was also a protection to the grillage; making, with its concrete filling of the walls and inside the coffer-dam, practically a broad caisson base upon which the cylinder shaft rested.

In reviewing the work it might be said that filling with concrete that portion of the wall space of the coffer-dam which was to be finally removed, was an unnecessary expense, and that clay would have answered quite as well; but the quantity of concrete being small, the security to be derived from the increased stiffness of the wall was considered ample justification for the expenditure.

During the entire progress of the work no trains were delayed to exceed 15 minutes, and this was of rare occurrence, being always in the case of an extra train or delayed freight, whose time of arrival was not known.

The confined space at all times hindered the work, and some unnecessary precaution may have been taken to prepare for possible emergencies; but those who are familiar with the rivers of the Southwest will appreciate the necessity for an excess of caution, and it was a frequent occurrence for all hands to be called at night to break up and remove fields of drift which had lodged against the false work.

The total estimated weight above the grillage at extreme low water, assuming concrete to weigh 150 lbs. per cubic foot, is:

	Pounds.
Cylinder shell	67 124
Concrete and coping	3 076 024
Superstructure and train load	825 750
Total	3 968 898
Less buoyancy of submerged portion	130 257
Total net weight	3 838 641

or 4 896 lbs. per square foot of interior coffer-dam space. Deducting the weight supported by the cylinders of the old pier, and assuming that the balance of the weight is supported by the piling alone, it gives 38 288 lbs. as the weight supported by each pile in the coffer-dam.

Including all material used for coffer-dam, platforms, staging, barges and general work, the total cost of the work is shown by the following detailed statement, the entire accounts for labor and material having been kept separate from the regular accounts of the bridge and building department.

Detailed Statement of Material.

Timber, 198 118 ft., B. M., at \$13.98	\$2 769 36
Piling—	
Cypress, 90 pieces, 55 ft. long, at .12 cents	606 00
Pine, 50 " 50 " at .06 "	150 00
Cement—	
English Portland, 1 000 bbls., at \$2.48	2 480 00
Louisville, 462 " at .85$\frac{4}{10}$ cents	394 90
Cylinder shell and rivets, $\frac{5}{16}$-in. steel, 67 124 lbs., at 3.74 cts.	2 510 44
Iron shoe (plates and angles), $\frac{5}{16}$-in. iron, 18 917 lbs., at 2.78 cents	525 27
Concrete stone, 750 cu. yds., at 75 cents	562 50
Rock (for concrete and rip-rap), 75 cars, at \$5.886	441 45
Sand, 57 cars, at 80 cents	45 60
Clay, 35 cars, at \$3.23$\frac{1}{2}$	113 20
Coping stones	517 84
Oakum, 10 bales, at \$2.68	26 80
Iron, spikes, bolts, etc	562 84
Tools	801 35
Sundry supplies and bills from other departments	685 21
Freight and transportation charges	612 75
Labor—including engineering and superintendence	11 703 06
Total	\$25 508 57

Analyzing this statement, we find:

Original estimate	\$30 000 00
Lowest bid	42 000 00
Highest bid	50 000 00
Actual cost by company forces	25 508 57

or \$4 491 43 less than the estimate, and \$16 491 43 less than the lowest bid received.

The labor represented 45$\frac{88}{100}$% of the total cost; the tools, 3$\frac{14}{100}$%, and the material and supplies, 50$\frac{98}{100}$. The Hayward dredge and Nye pump were rented; the balance of the machinery and tools was either purchased new, or taken from stock in the Bridge and Building

Department, and all material and tools left over upon the completion of the work were taken back, and no credit given in the general accounts.

No sign of settlement or scour has ever occurred, but, on the contrary, when the false work was finally removed, the river commenced filling in around the pier, and the cross-section of the river now indicates a more stable channel than ever before.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

696.

(Vol. XXXI.—March, 1894.)

LINING A WATER-WORKS TUNNEL WITH CONCRETE.

By DESMOND FITZGERALD, M. Am. Soc. C. E.

READ FEBRUARY 7TH, 1894.

WITH DISCUSSION.

Description.—The Sudbury River Aqueduct, supplying Boston with water, extends from Farm Pond in South Framingham in an easterly direction to Chestnut Hill Reservoir in the suburbs of Boston, a distance of 15.9 miles. It is 9 ft. wide, 7 ft. 8 ins. high, and has a fall of 1 ft. to the mile. Its capacity is 100 000 000 galls. daily. Near the reservoir it passes through Beacon Street Tunnel in conglomerate rock, nearly one mile in length, and excavated in 1875. The conglomerate is crossed by strata of slate in places. This slate underlies the Boston basin, and is interrupted in the great Newton syncline either by an elevation above the present plane of erosion, or, as has been suggested by Professor Crosby, by a thrust fault. In 1877, it was found that disintegration had begun at a few points, and at this time a side wall 50 ft. long at Station 806, and 260 ft. of brick arching, in two separate sections, between Stations 810 and 813, were built in the tunnel.

The following is an extract from the report of Professor Raphael Pompelly, made at that time :

"The Beacon Street tunnel is in Roxbury conglomerate, and its axis is so nearly in the direction of the course of the bedding that where it strikes a narrow bed of the interstratified slate, this rises very gently, forming first the floor and one wall, then part of the other wall and roof, and finally disappearing above the tunnel roof. At several points this slate is much broken, and small quantities are liable to fall in, especially the north wall at 804 + 42, the south wall between 806 + 45 and 806 + 85, and the south wall at 810 + 50 to 810 + 80.

"But the nature of the roof and the character of the joints are such that there need be no fear that this will endanger the safety of the tunnel. There are only two points which seem to call for attention :

"*First.*—From 810 + 10 to 810 + 50 there are several joints in the roof running nearly in the direction of the tunnel and converging upward. The conglomerate has changed to-day along these seams to a depth of several inches; the decomposition of the rock and the position of the joints render the roof and walls insecure at this point, and I should recommend that this portion be arched.

"*Second.*—From 812 + 70 to 812 + 90 the roof has caved in to the height of 18 to 20 ft., owing to the horizontal columnar structure of the rock. I was not able to test the soundness of the rock in this dome, but it is not improbable that more rock may fall. The walls are good, and it seems to me that this might very properly be left undisturbed for the present. Should it be found necessary in the future to arch this point, the skew-backs could be cut in the walls above the level of the flowing water, and the arch could be built without interrupting the supply."

For several years afterwards small portions of the roof gave way, and it became evident that it was only a matter of time when it would be necessary to line portions of the tunnel.

In June, 1888, six cartloads of rock which had fallen were removed, and before the close of the year a large number of heavy pieces fell. It was decided to begin repairs at once,and before the increasing consumption of water in the city might form a serious obstacle to the undertaking. To show that the work was taken in hand none too soon, it may be added that 20 cartloads were removed in 1890, and that in December, 1890, during the work of lining, a mass of rock fully 10 tons in weight fell, demolishing the track and a switch, but fortunately injuring no one; other dangerous portions were braced up until they could be sustained permanently by the lining.

Preparations for the Work.—As it was necessary to maintain the

supply of water to the city during the construction of the lining, it was realized, before the plans were made, that the work would be difficult and would require careful thought in regard to every detail. Cross sections of the tunnel were taken, and it was found that in one place the roof had fallen to such an extent that it was 10 ft. above the average roof line. An estimate of the probable cost was based on lining at least 650 ft. of the dangerous portions, requiring about 2 500 cu. yds. of concrete. An outline of the scheme developed consisted in laying a track about 2 ft. above the bottom of the tunnel, taking the materials to form a lining of Portland cement concrete to the work in special cars, and mixing them close to the centers, the latter to be so designed that the cars, and also large flows of water, could pass through them.

The stations of the aqueduct begin with 0 at the westerly end, at Farm Pond, and extend in an easterly direction to the terminus at Station 838 + 32. The tunnel lies between Stations 776 + 65 and 823. There were three points of access to the aqueduct in the vicinity of the tunnel, one at Clarks' Waste Weir, Station 738 + 15; one at Station 772 + 80, near the westerly end of the tunnel, by means of a large gauging manhole; and the third by a manhole at Station 824 + 75, near the easterly end of the tunnel.

In June, 1889, shanties were erected at these two manholes, a ledge was opened in Newton Centre, a crusher set up, and in July about 50 tons of old rails, weighing 36 lbs. to the yard, were collected and delivered at Clarks' Waste Weir, which was the nearest opening of sufficient size to get them into the aqueduct. These rails were here straightened, drilled, where necessary, for the fish plates, and the switch rails curved to the proper radius.

The Track.—It was determined to make the track as perfect as possible, and it was fortunate that this was insisted on, for after several years' use it was still in as good condition as when first laid, and it never gave trouble. The gauge was 2 ft. 1¼ ins. When the rails were ready, the iron floor was removed from the gate house at Clarks' Waste Weir, and an inclined plane built leading down to the floor of the aqueduct. The rails were slid down to two cars prepared for the purpose. The iron wheels were covered with broad oak rims, which were beveled to conform to the invert of the aqueduct, and were also provided with guide wheels at the front and rear, projecting to the sides of the aqueduct, to keep the cars in the center. Twelve 30-ft. rails were trans-

ported at a load. On arriving at Station 772 + 30, the westerly end of the track, they were transferred to a two-wheeled cart, fitted with a long plank trough, carrying four rails to a load, and by means of these carts the rails were distributed along the line. The necessity for this transfer was on account of the change from the curved invert of the aqueduct to the level floor of the tunnel. The iron tires of these wheels were also covered with oak rims, to prevent injury to the con crete floor of the tunnel. This floor had been originally constructed by leveling up with débris and covering it with a 4-in. layer of concrete. The easterly end of the track was at Station 810 + 50. Length of track, 3 820 ft. There were four switches 50 ft. long, making total length of track and switches 4 020 ft. The average distance the rails were transported inside the aqueduct was 5 340 ft., and, when finally placed, they had been loaded and unloaded 13 times, and a portion of the work done in water 1 ft. deep, for it was not possible to wait until the water was all drained out of the aqueduct before beginning work.

The rails were supported on 500 trestle frames 8 ft. on centers. These trestles were made outside and transported by the same method used for the rails. The fall of the aqueduct in the length of the track was 8.7 ins. An additional pitch of 5 ins. was added in the construction of the trestles, giving 13.7 ins. total fall to the track, which made the pushing of the full cars an easy task. The trestles were built of 3 x 4-in. spruce joists. The two vertical supports were placed directly under the rails, and the union between the horizontal and vertical members was made by means of 1 x 3-in. strips, placed on both sides and fastened with 10-penny wire nails. There were also 1 x 3-in. pieces uniting the bottoms of the vertical joists. One-third of the trestle caps were made long enough to extend out to the sides of the tunnel, where they were wedged against the rock to keep the track immovable. The extremities of these pieces were braced down from above to keep the track from being floated when water was running. The other trestle caps were 5 ft. long. They carried a plank 2 x 10 ins. on each side of the track and two in the middle for the men to walk on. The trestles were provided with 1 x 3-in. diagonal braces, extending from the bottom of one trestle to the top of the next, and in reversed order on the other side. There were 10 000 ft., B. M., in the trestles, and 27 000 ft., B M., in the planking. The latter were floated from Clarks' Waste Weir. The rails were fastened to the trestles by means of a clasp $3 \times 2 \times \frac{3}{16}$ ins. and

a $\frac{3}{8}$-in. bolt 4 ins. long, and to each other by the usual fish joints. The switches were placed at convenient points for passing, and where the tunnel was wide enough to permit of their construction. They were provided with red and green lanterns for signals. This elevated track allowed certain portions of the work to be carried on independently of the water running in the bottom of the tunnel. The cost was \$3 324 32.

The Cars.—The cars were ten in number, seven for transportation of materials, two for transferring the concrete from the mixing beds to the lining, and one for miscellaneous use, such as moving centers, etc. The wheels were 20 ins. diameter inside the flanges, and 22.5 ins. on the flange. They were 2.5 ins. wide on the rail, and the flange was 1 in. thick, making total width 3.5 ins. Each wheel had six spokes. The axles were 2 ins. diameter, keyed solidly to the wheels. The bearings for the boxes were turned to 1.75 ins. The boxes were held in position by four bolts, two of which secured the upper part of the box to the frame work of the car and two others secured the lower half to the upper half ; openings were provided for oiling the bearings.

The framework of the car was 5 x 1 ft. 9 ins. and was made of 3 x 6-in. and 3 x 4-in. oak material, and tenoned. A $\frac{5}{8}$-in. iron rod held the frame together at each end. An additional oak frame, 3 x 4 ins., was bolted to the frame proper to support the plank platform which consisted of three spruce joists 2 ft. 6 ins. long laid crosswise and planked with three 2 x 10-in. spruce planks 9 ft. 6 ins. long, projecting at each end of the car for the men to stand upon while unloading. The outside planks were bolted down, the center one being left loose for removal when oiling the bearings. Flaps of leather protected the oil holes.

The four cars which were to be used for the transportation of stone were provided with boxes 7 ft. 3 ins. long at the top and 4 ft. 9 ins. at the bottom, 2 ft. 6 ins. wide and 1 ft. 1 in. deep inside dimensions; capacity, level full, five casks of crushed stone. The ends of the boxes were made slanting to facilitate emptying. The three cars for the cement and sand were fitted with similar boxes, with the exception that they were 1 ft. 9 ins. high and were divided by a partition to separate the sand from the cement. These boxes held exactly two casks of cement and four casks of sand; they were made from spruce planks spiked together and fitted with two $\frac{1}{2}$-in. rods at each end, to prevent spreading. The ends were also set at an angle for convenience in unloading. The

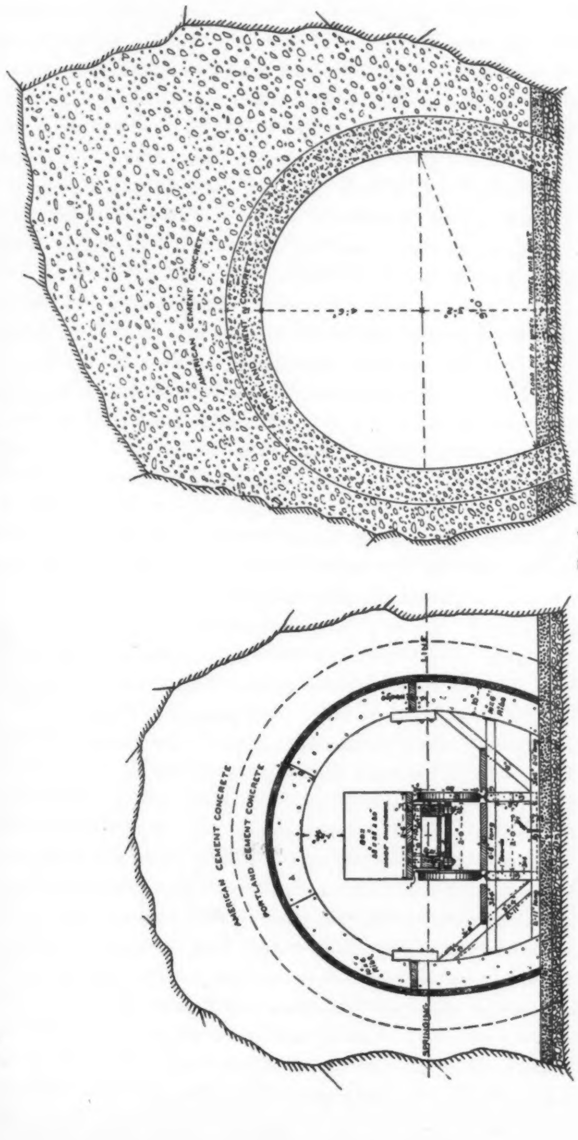

AMERICAN CEMENT CONCRETE
PORTLAND CEMENT CONCRETE
AMERICAN CEMENT CONCRETE
PORTLAND CEMENT CONCRETE
LINE
SPRINGING

FIG. 1.

concrete boxes were 9 ft. 4 ins. x 3 ft. 10 ins. x 1 ft. 1 in. deep and of sufficient capacity for one batch of concrete mixed 1, 2 and 5 These cars had no ends. The sides were held in position by three iron bands passing beneath the bottom, extending up against the sides and and bolted to them. The cars cost $557 54.

Centers.—As no bracing could be used, the centers were designed of great strength. They were to be spaced 2 ft. on centers, but it was found that they were amply strong for 4-ft. spans, and they were so used. They were built of three thicknesses of spruce planks, breaking joints, and nailed with 4-in. wire nails. When completed they measured 5¼ ins. wide by 10 ins. deep. They were in three parts. The two side sections when in position extended from the bottom of the tunnel to 4 ins. above the springing line. The upper part was 6 ins. short of a full semi-circle. A 2-in. space allowed the introduction of wedges between the upper and the lower sections. The latter were triangular in elevation, with bases 3 ft. 8 ins. long, and braced diagonally. When set up the bases met in the center of the tunnel and were separated by a wedge. The side sections were united to the arch section by 3-in. oak blocks 5 x 14 ins., bolted by two ¾-in. bolts and one ⅝-in. bolt in the lower sections, and two ⅝-in. bolts in the upper center. Spruce board wedges 1 x 3 x 8 ins. were used in setting the forms.

There were 75 full centers containing 8 175 ft., B. M.

The lagging was made from 2 x 4-in. spruce joists in 8-ft. lengths, planed on both sides, with the edges beveled to fit the centers and secured with 10-penny wire nails. This lagging formed a tight cover over the centers. The total amount of lumber in centers and lagging was 14 000 ft., B. M., and the total cost was $1 460 55.

Shanties.—Sufficient shanty accommodation was not provided at first, but, as finally developed, the shanty at the westerly end, Station 772 + 80, was 100 ft. in length by 20 ft. wide, 7 ft. 7 ins. to the plate, with a lean-to on each side 12 x 22 ft. The frame was built of old materials, and the walls and roof of matched spruce boards. The roof was covered with tarred paper. It was found that the work of lining the tunnel could be carried on much better in the winter than in the summer, contrary to what was expected. As it was necessary for the laborers to wear heavy clothing for protection, and the heat from torches and lights was considerable, and the space for working very cramped, the men could carry on the work with less discomfort in the

winter when the air was comparatively fresh and cool and the ventilation good. After a little experience it was found perfectly feasible to supply materials for concrete free from frost even in the coldest weather. This, however, required considerable storage room in the shanty. The building was divided into compartments to contain 500 casks of cement, 160 cu. yds. of sand, and 80 cu. yds. of crushed stone and 80 cu. yds. of screenings from the gravel pit. At one end a large drying-room for the use of the men was provided. The gasoline and kerosene oil were kept in an out-building.

Shutes led vertically from the shanty down the manhole, terminating just over the cars beneath.

In the center of the sand compartment a large stove was surrounded by a deep plank bulkhead lined with iron, and the sand was piled all around it. By keeping up a fire in the coldest weather, the sand was kept free from frost.

The crusher was kept going at convenient times, and a large pile of crushed stone was kept on hand. It was covered with canvas, to keep out the rain and snow, and from time to time one of the lean-tos was filled from this pile and the other was filled with screened gravel. The screenings could not always be used on account of their arriving in a damp condition, when they were liable to freeze.

The cost of the shanties was $1 289 38.

Mixing Beds.—There were four mixing beds, each 15 ft. long, 5 ft. wide, and 10 ins. deep. They were built so that the boxes containing the materials on the cars projected over them, preventing waste of materials in loading and unloading. They were elevated above the floor of the tunnel on strong wooden horses and were built as high as possible, in order to reduce the lift to the smallest amount in shoveling the concrete into the cars. The widest and highest sections of the tunnel were selected for these mixing beds, and they were placed as near the work as possible. A board shelter covered with canvas kept them protected from the drip from the roof of the tunnel and they were securely braced. They contained 3 000 ft., B. M., and the cost was $303 47.

Equipment of Men.—Each man was furnished with a pair of long rubber boots, an oil jacket and a lantern. The articles were all numbered, and a record kept, with the name of the workman having them in possession.

Construction.—As work inside the tunnel could only be carried on for four days in the week, and a large flow of water had to be run during the other three days, to make good the loss in the reservoir, the work of laying the track occupied the greater part of the summer. In September the shanty was stocked with cement, sand and crushed stone, and on October 15th the actual work of construction began.

The first work consisted in preparing the bottom. It was not thought wise to build the lining on top of the concrete floor with the dry filling underneath. To cut all the sides out would have cost a large amount of money, so piers were cut out 8 ft. long with an 8-ft. space between them, and breaking joints on each side of the tunnel. The faces of the piers were stopped 2 ins. short of the face of the lining, thus breaking the joint over the edge of the opening. All the filling under the concrete floor, consisting of broken stone, gravel, sand and clay, was removed to the solid rock.

As the water was always from 3 to 6 ins. in depth on the floor of the tunnel, it was necessary to lay sand bags around these excavations. The water came in so rapidly as to require constant pumping. The average pier contained 16 cu. ft. of concrete.

A dam, to regulate the water in the tunnel and keep it from flooding the work, was placed at Station 782, west of the work of repairs. The top of this dam was 2 ins. below the bottoms of the rails in the track. This dam accumulated the waters of percolation until they were raised sufficiently high to reverse the flow under the track, allowing it to escape at Clarks' Waste Weir. By this means, also, an abundant supply of water was always at hand for making the concrete. The dam was fitted with two large valves. When desired, a second dam was placed easterly from the first and located between the mixing beds and that part of the tunnel where the concrete was being deposited. The water was thus kept at its lowest point where the centers were being placed. From the second dam the in-filtering water could drain off freely to a plug connecting with a sewer at the terminal gatehouse at the reservoir. The valves were partially opened at night, to prevent an overflow during the day; and were taken out when the flow of water was let on at the end of the four days' work.

Disposition of the Force.—Two men were kept at the bank screening sand and preparing stone and screenings, one man in the building shoveling sand, two men shoveling crushed stone, one man opening

cement, spreading it upon the floor and picking out the paper and shoveling it down the slide. This man also attended to the gasoline torches and lanterns for the switches; he also carried the torches to the work in the morning and back at night. There were seven men on the cars and sometimes eight, transporting the materials to the mixing beds. A foreman and five men were stationed at the mixing beds, two men ran the concrete cars from the beds to the work; two additional men helped unload; four men were employed in laying and ramming; four men digging the foundation piers, removing débris, pumping water, washing the tunnel, and preparing the centers; three men taking down centers and setting them up and helping carpenters; three men taking nails out of lagging, scraping and washing it, and three carpenters setting centers, building drains, weepers and bulkheads. Whole number of men, including superintendent, 41 men for four days, weekly. On the remaining two days in the week, the aqueduct being then half full of water, a portion of the force was occupied in crushing stone and filling the supply buildings, and the remainder, with the carpenters, were provided with work elsewhere.

Portland Cement Concrete.—As the lining was to consist wholly of concrete, it was of the utmost importance that it should be of good quality. Some experiments were made to determine the actual proportions of the materials as used. It was found that in dropping 12 ft. down the spouts to the car, some consolidation of the crushed stone and sand took place. As two casks of cement were always emptied down the spout into each car, irrespective of the space they occupied, these two casks remained unchanged, but rather more than four casks of sand were shoveled down, to fill the sand compartment of the car. Two casks of sand shoveled into a measuring box at the surface of the ground were found to occupy a space of 6.84 cu. ft., and in the car (12-ft. drop) 6.37 cu. ft., a shrinkage of 7 per cent. Five casks of crushed stone, well screened, filled 16.87 cu. ft. at the surface, and in the car 15.31 cu. ft.; a shrinkage of 9 per cent. Consequently, as enough material was shoveled down to fill the car, we have 18.56 cu. ft. of crushed stone and 7.35 cu. ft. of sand used with every cask of cement, making, when taken out of the car and spread in the mixing beds, a proportion of one cask of cement, as it came from the dealer, two and one-sixth casks of loose sand, and five and one-half casks of loose crushed stone. By slightly shaking the sand and stone in the casks it was found that

this amounted practically to the proportions of 1, 2 and 5. By actual measure this was found to make 20 cu. ft. of concrete when thoroughly rammed. The crushed stone was somewhat smaller than the average size. The concrete was of exceptionally good quality, as was determined by inspection of large sample blocks. One of these blocks, containing 20 cu. ft., was drilled through in three places, and opened by means of long steel wedges driven from two sides, and found to be perfectly solid and free from voids.

The concrete was hardly compacted as solidly in the tunnel, and there it occupied 21 cu. ft. per cask of cement, 1.3 casks of cement laid in 1 cu. yd. of concrete.

Mixing.—Each batch of concrete was mixed by spreading five and one-half loose casks of crushed stone evenly to a depth of 5 ins. in the mixing bed. One cask of cement was then spread over the stone, and two and one-sixth casks of coarse bank sand on top of the cement. These materials were then mixed, in a dry condition, the men being required to show the backs of their shovels turned evenly upwards at each cast. This part of the mixing was done in advance by one man, while a wet mixing was going on in another bed close by. The wet mixing which came next was performed by four men. One man applied the water, while one man on each side turned the concrete towards the center of the bed, while the fourth man behind the others did the same. The concrete, after having thus received one dry and one wet mixing was then shoveled into the two concrete cars, which were then run to the work, one man to each car. On arriving, another man was detailed to each car, and the concrete was shoveled into place.

The four men who did the laying and ramming were obliged to use great care to insure thorough work, for the coarser portions always had, as usual, a tendency to fall against the lagging. If these had remained, the exposed surface of the arch, on removal of the lagging, would have been full of cavities, and it would have been almost impossible to have resurfaced the work.

It was originally intended to use Portland cement concrete for a distance only of 1 ft. from the lagging, and to back it up with American cement concrete. Where there was a considerable space to fill, this was practicable, but ordinarily it was found cheaper to use Portland

PLATE XLI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXI, No. 696.
FITZGERALD ON CONCRETE TUNNEL LINING.

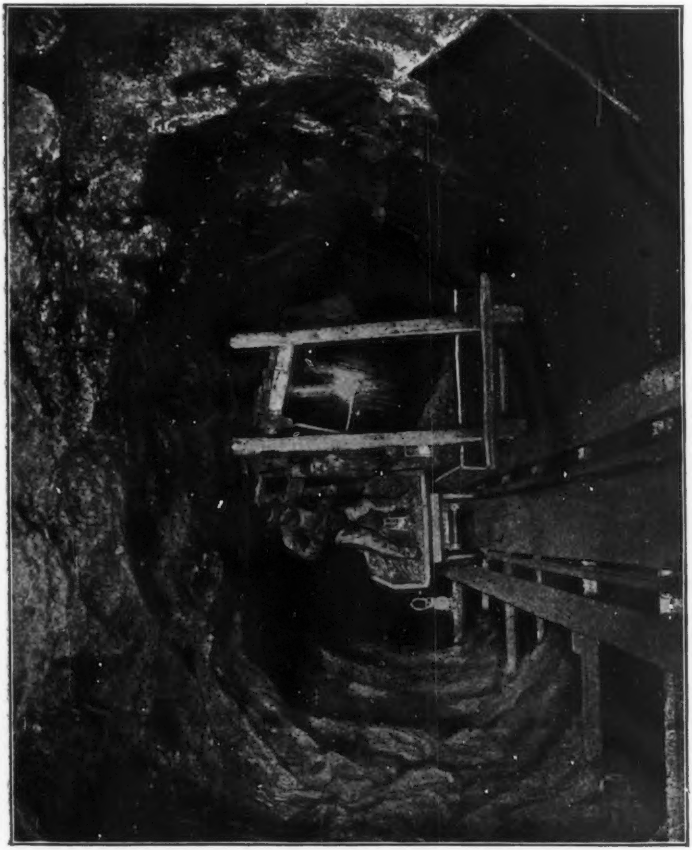


PLATE XLII.
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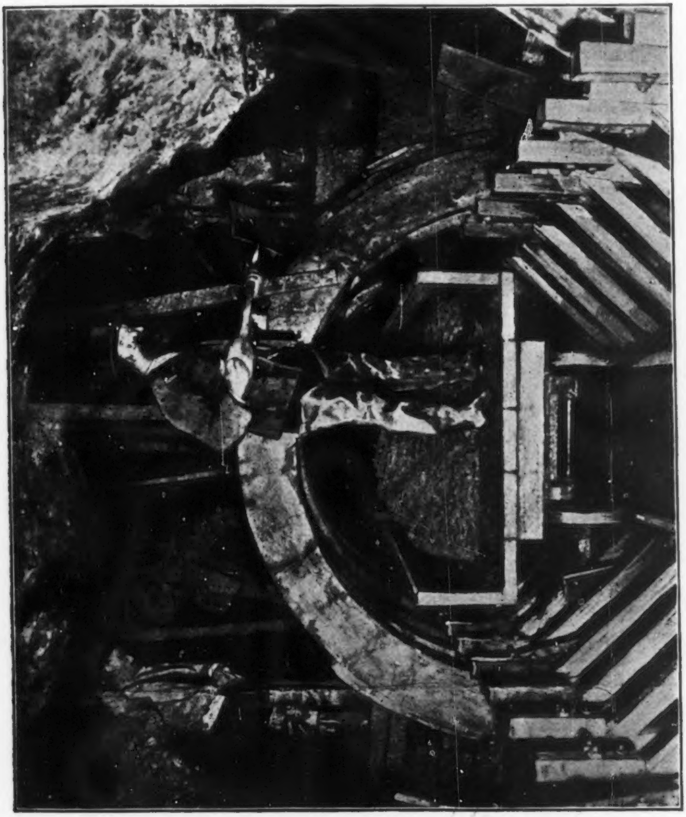

cement entirely, owing to delays, lack of room and other difficulties. The different portions of the work were so closely related that a stoppage in one place caused a disarrangement of the whole system. When changing from one cement to the other on the sides, it was necessary to build bulkheads, and these had to remain in place until the concrete had set. The filling of the space near the top of the roof of the tunnel was the most difficult part of the work, as the men had to work in a crouching attitude and push the concrete with long-handled implements into all the crevices.

The average number of casks of material put into the work daily was 192. This was transported an average distance of 2 700 ft. Seven men did this work; one load consisted of one car of stone and one car with the cement and sand, and this load contained 11 casks. Three men pushed these cars, and made eight trips per day (88 casks). The second gang of three men made seven trips per day (77 casks), and the gangs alternated daily. An additional stone car was run by one man, averaging 27 casks daily. Distance traveled per man per day propelling cars, 7.66 miles. Each man also shoveled from the cars 27.4 casks of material, spreading it evenly into the mixing beds. The loaded cars had the right of way. The returning cars were obliged to make quick trips from switch to switch.

Tools.—The concrete was put in place with shovels and rammed with rammers of various forms, the principal ones being made from oak timber 5 ins. square, 12 ins. long, with a 2-in. handle, 30 ins. long, inserted in one end. The concrete was pressed into the cavities in the roof with long-handled T-shaped implements, the iron portion being 3×8 ins.

Weepers.—Large quantities of water poured from the roof in rainy weather in certain places, and it was found necessary to build many weeping drains into the concrete. They were built of spruce boards, 6 ins. wide, in 4-ft. lengths, and were placed on both sides of the tunnel, 16 ft. apart. The first lengths were laid on the bottom, extending through the centers and cut off flush with the lining. Vertical sections fitted against the walls connecting with the bottom sections. The sides of these boxes next the walls were open, with the exception of the first vertical section and the horizontal section, which were tight, to prevent the escape of cement.

Bulkheads.—Bulkheads were usually 16 ft. apart lengthwise of the tunnel. They held the concrete in place while it was rammed and during setting. Bulkheads for the arch were 4 ft. apart. Steps were formed in each section of the concrete lining by means of bulkheads from 1 to 2 ft. wide and 20 ins. high. A bond was thus formed between the sections.

Arrangements for Running Water for the Supply of the City.—The water was shut off from the aqueduct on Sunday at 3 P. M. At 4 A. M., Monday, the gates at Fuller's Waste Weir, Station 459, were opened, and also at Clarks' Waste Weir, Station 738.

The depth of the water remaining in the aqueduct at this time was generally 7 ins. at Fuller's, and 16 ins. at Clarks'. Two stop planks across the aqueduct between the two gates at Clarks' Waste Weir separated the water wasting from the west from that wasting from the east which came from the dam at Station 782. Easterly from this dam the water escaped into the reservoir. At 7 A. M., Monday, the connection with the reservoir was closed and the plug leading to the sewer opened. Work in the tunnel was started at this time and prosecuted until Thursday evening.

At 2 P. M., Thursday, a flow of 50 000 000 galls. daily was started, arriving at the tunnel after the men were all out. This flow continued until Sunday at 2 P. M. It reached to within 1 ft. of the underside of semi-circular form. The gates at Fuller's were closed on Tuesday at 2 P. M. and at Clarks' at 5.30 on Thursday. The plug was put into the sewer at 10 P. M. and the water arrived at the reservoir at 11 P. M.

To prepare for this large flow, the cars were loaded with materials and side-tracked, other cars ballasted with sand bags and left upon the main track in a wide section of tunnel, centering braced down, lumber and tools scaffolded, chips and waste material gathered, and the sanitary (earth closet) removed.

Progress of the Work.—One thousand one hundred and eighty-two linear feet of tunnel lining were laid in portions of three different winters as follows:

October 15th, 1889, to April 18th, 1890	562 ft.
January 14th, 1891, to May 7th, 1891	340 "
February 1st, 1892, to April 6th, 1892	280 "

The following table of statistics refers to the three working seasons in order:

Season.	Days.	Linear feet.	Linear feet laid daily.	CEMENT. Number of casks. Portland.	Americau.	Total.	Average per day.	CONCRETE. Number of cubic yards. Total.	Average daily.	Cubic yards per foot.	EXPENDITURES. Total expenditures.	Price per cubic yard.
1st.....	89	562	6.20	1 715	349	2 064	23.19	1 605	18.04	2.85	$29 272 50	$18 24
2d.....	59	340	5.76	1 245	76	1 321	22.39	1 027	17.41	3.00	13 990 59	13 62
3d.....	38	280	7.37	1 009	61	1 070	28.00	832	22.00	2.98	12 679 63	15 24
	186	1 182	6.36	3 969	486	4 455	23.95	3 464	18.62	2.93	$55 942 70	$16 15

Cost.—The total expenditure on account of the lining of the tunnel, including cleaning up outside and inside after the work was completed, was $55 942 70. This expense included some work which might justly have been charged to other appropriations; but, on the other hand, there are always some expenses under conditions similar to these which do not get into a force account, however methodically kept. This makes the cost per cubic yard $16 15, which the writer believes to be moderate in consideration of all the circumstances. The track is now in the tunnel, ready to be used again, should any other portions of the tunnel require repairs in the future. If the taking out of the track is to be charged to the work already done, the price named above is not quite sufficient.

The foreman in charge of construction was Mr. J. W. Oldham, and the writer desires to record here his appreciation of the skill and fidelity with which he superintended and executed the work.

DISCUSSION.

R. W. LESLEY, Assoc. Am. Soc. C. E.—I should be glad to know if any record was kept of the proportion of water used, and what proportion of sand and broken stone went to make the concrete. There have been so many different figures on this, so that recently a leading

contractor took a contract for concrete in which he figured that he was going to use so many parts sand, so many parts stone, so many parts cement, etc., and that as the sum of these materials made so many cubic feet it would cost him so much per square. As he had omitted to figure that the cement and sand filled the voids in this stone he came $33\frac{1}{3}\%$ short on what he expected to get for his work. As these are the first figures I have seen on this subject I would be very glad to know if there were any figures on the water, so that we would know how much of the various ingredients would make a yard of concrete. It is a very interesting problem, now, to determine exactly what is required to make one yard of concrete of a certain proportion.

Mr. FitzGerald.—A great many accounts of concrete ingredients have been published. I regret to say that we did not keep any account of the water, but my instructions were to mix the concrete for each batch as dry as it could be worked, and to ram it very thoroughly.

Mr. Lesley.—The concrete, as it was rammed, brought the water to the surface, as I understand. The figures, according to your paper, would give about 30 cu. ft. of material, excluding water; a barrel of cement is equivalent to about 4 cu. ft.

Mr. FitzGerald.—Yes; 29.4 cu. ft. made 21 cu. ft. of concrete with one cask of cement, or 38 cu. ft. of materials made one cubic yard of concrete with one and one-third casks of cement. A singular fact is that if you get a pile of broken stone together and measure the voids carefully and put in enough cement and sand to fill those voids, it more than fills them.

Mr. Lesley.—I have made some experiments to determine the water in concrete. The great question in the experiments I conducted was the porosity of the lime stones and trap rocks we used. I found from our experience the only way was to make a box of a given size and actually determine what went into the box, each rock requiring different proportions of water. I see you took the run of the crusher.

Mr. FitzGerald.—True, it was not passed through a ring, but it was all screened through a circular screen to a definite size.

Mr. Lesley.—The figures are very interesting and the first I have seen on that particular question.

Mr. FitzGerald.—I have had some blocks of concrete mixed containing about 1 cu. yd. These were broken open by boring three holes clear through them in the same plane and inserting long, thin steel wedges. The blocks were found to be perfectly solid and free from voids, but how water-tight I cannot state.

Mr. Lesley.—On the subject of the permeability of mortar there were some figures made and published by the Engineering Department of the University of Pennsylvania, giving the permeability of various mortars and cements.

Mr. FitzGerald.—How did they get the porosity?

Mr. Lesley.—They took little cylinders of the material and then put on the pressure from an ordinary water pipe, the discs were put in the water pipe and the pressure was allowed to go through them. I have that record on some twenty or thirty different materials.

Charles B. Brush, M. Am. Soc. C. E.—I am very glad that Mr. FitzGerald has given us the results of his work in such detail. I feel especially interested in this paper because I personally urged Mr. FitzGerald to present it to the Society. There are several question, I should like to ask. What was the number of cubic feet in a cask? I notice that those two casks of sand shoveled in the measuring boxes show that two casks of sand occupied a space of 6.84 cu. ft., and five casks of crushed stone 16.87 cu. ft. This would seem to indicate that it was 3.42 cu. ft., and the five casks of crushed stone will give 3.37.

Mr. FitzGerald.—I am much obliged to Mr. Brush for calling attention to this matter. The measurements given were averages of a number of measurements, and without any attempt to fudge them to an agreement when reduced to the same unit. The contents of a cask were accurately determined, however, by putting it into a box surrounded with concrete and then filling the cask with water. It took just 25 galls., 2 qts. and 1 pt. to fill the cask between the heads, and this gives us by calculation 3.425 cu. ft., which represents the quantity of cement and paper as they came from the manufacturer. That the measurement of the sand (see page 303) should have agreed with this exactly is a mere accident. It should really have measured a little more, because one head was out of the cask. The sand, after being filled into the cask, was taken out, and, for tests, measured in a rectangular box. The same was done with the crushed stone, and that one measured 3.42, and the other 3.37 when reduced, shows how carefully the measurements were made.

Mr. Brush.—I would like to ask what brand of cement was used in this work; whether the same brand was used throughout or whether different brands were used?

Mr. FitzGerald.—We used mostly Brooks, Shoobridge & Co.'s cement. It gave $36\frac{7}{10}$% retained by No. 120 sieve* and, with 22½% of water, gave an average tensile strength of 388 lbs. neat, and, with 2 parts sand and 13½% of water, gave 51 lbs., and, with 3 parts of sand, 12% water, gave 21 lbs., and with sand, 3, cement, 1, 312 lbs. in compression. All seven-day tests.

Another series of tests gave 30½% retained by sieve 120, and 182 lbs. tensile strength neat cement, 24 hours, 22% water. Sand, 1, cement, 1, one day, 65 lbs., 14% water, and 250 lbs. at the end of seven days. With 3 of sand and 12% water, 90 lbs., seven days, 147 lbs., 28 days, and 380 lbs., per square inch compression strength, seven days.

Mr. Brush.—A slow-setting cement?

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* 106 and 116 meshes to the inch each way by actual count.

Mr. FitzGerald.—Rather slow, about 50 minutes to take the heavy wires; slower than the Alsen, but not nearly as slow as the German and French cements, which take sometimes seven hours to bear the heavy wire.

Mr. Brush.—Referring to the diagram, it would seem that at places there was a very large space between the arch and the rock excavation.

Mr. FitzGerald.—That is where the roof had fallen.

Mr. Brush.—About what was the average over the arch?

Mr. FitzGerald.—I don't think the average would be over 2½ ft.

Mr. Brush.—As I understood you when you read the paper, the filling in was all done with Portland cement instead of American cement, except in the deep pockets.

Mr. FitzGerald.—Yes.

Mr. Brush.—I would like to ask whether the results might not have been obtained equally well by using dry stone filling instead of concrete filling; whether it would not have largely reduced the cost.

Mr. FitzGerald.—Undoubtedly it might have reduced the expense, but we thought it would be better to make the work homogeneous, as those deep pockets were not very long. There could then be no question about the permanence of the repairs. The percolation of water might have brought enough oxygen down with it (especially in the winter when the water contains so much more oxygen) to have produced some farther disintegration; still that is a conjecture.

Mr. Brush.—Was the percolation considerable ?

Mr. FitzGerald.—It was in streams in some cases.

Mr. Brush.—Where you struck it in streams, did you convey it directly into the drains ?

Mr. FitzGerald.—Yes, and the drains emptied into the aqueduct. That leads to a very interesting question if you follow that up.

Mr. Brush.—I was leading up to that question. I would like very much to know your views on that subject.

Mr. FitzGerald.—I do not believe very much in building aqueducts below the levels of the water tables of the country through which they pass. I think an aqueduct to convey drinking water should not do this, because I know from many years of experience there are places where a great deal of contamination comes from the ground-water flow into an aqueduct. It is one of the elements that I think a man ought to consider in designing new work.

Mr. Brush.—The dry stone lining under the concrete floor was, I suppose, the débris that was in the tunnel ?

Mr. FitzGerald.—Yes.

Mr. Brush.—And then this floor was laid solid from the face of the rock on each side of the excavation ?

Mr. FitzGerald.—Yes.

Mr. Brush.—And the arch was sprung from there ?

Mr. FitzGerald.—For a length of 8 ft. the new work was carried down to the solid rock, then for the next 8 ft. it rested on the floor, alternating in this way in the length of the tunnel.

Mr. Brush.—The floor, then, was already in ?

Mr. FitzGerald.—Yes, and in order to get a good foundation for the lining I took the floor out in the shape of these piers, and connected with the solid rock at the bottom.

Mr. Brush.—Did you find the flooring in good condition ?

Mr. FitzGerald.—Yes; but you must bear in mind that there was dry filling under the thin concrete floor. I was not willing to build wholly on top of this floor.

Mr. Brush.—You will, perhaps, leave this staging in the aqueduct some time yet ?

Mr. FitzGerald.—No; as soon as we got one section laid, we kept pulling down the centers back of us and building them forward.

Mr. Brush.—Did you not pull down the platform ?

Mr. FitzGerald.—No; the track was entirely independent of everything. We did pull up our track when we had 2 000 ft. laid, removing all track up to that point; the tunnel was completed then.

Mr. Brush.—How long after you finished any portion of this arch did the water come in contact with it ?

Mr. FitzGerald.—On some portions almost immediately; on others within three days. If you give it about 24 hours set, then the fine finish at the surface will remain; but if you allow the water to run over cement work within 24 hours, the body of the cement will stand, but the fine gloss disappears from the surface.

Mr. Brush.—In laying this concrete, what thickness did you make your layers?

Mr. FitzGerald.—We kept it in one homogeneous mass, going right along and filling it in.

Mr. Brush.—Ramming it up against the sides?

Mr. FitzGerald.—Yes; stepping it up.

Mr. Brush.—Going along the back, did you keep the layers horizontal?

Mr. FitzGerald.—Yes; of course we had to vary them a little, and to build a great many bulkheads.

P. F. Brendlinger, M. Am. Soc. C. E.—Mr. FitzGerald says: "In 1877, it was found that disintegration had begun at a few points, and at this time a side wall, 50 ft. long, at Station 806, and 260 ft. of brick arching, in two separate sections, between Stations 810 and 813, were built in the tunnel." What was the objection to continuing the brick arch in this place where there was a concrete arch put in?

Mr. FitzGerald.—The brick work would have cost a great deal more money; that is the only reason. I designed originally to make this arch of brick, and back it up with concrete.

Mr. Brendlinger.—Why back it up with concrete? In a contract for brick work in a tunnel now building, the cost is about $8 a cubic foot; this cost $16.

Mr. FitzGerald.—The cost was owing to the conditions. The brick work would have cost still more; the cost of this work came from the conditions under which it was performed.

Mr. Brendlinger.—The New York Aqueduct was built in various types of section, but I don't know why. The arch was all brick work, and the rubble masonry backing was carried up to about half way between the springing line and the center. The remaining space was filled up with dry packing to a thickness of 4 ft., in some cases. Now, it seems to me that under the circumstances and conditions you worked under, a brick tunnel could have been built much cheaper than the concrete. As to the question of getting material in, you can make eight trips a day; it is not one mile to haul.

Mr. FitzGerald.—The tunnel was about one mile long.

Mr. Brendlinger.—Eight trips a day is not much; some of the men went but seven trips a day; that could not have been much more than half a mile.

Mr. FitzGerald.—I think I have given the exact distances, but, of course, you can get them from the stations. It must be remembered that, as stated in the paper, these men who pushed the cars did other work.

Mr. Brendlinger.—It looks to me as if the material could be put in there sufficiently fast so that there could be probably 30 ft. of arching completed in 24 hours, in brick work.

Mr. FitzGerald.—We allow for concrete $6 00 per cubic yard, and you cannot do brick work for anything like that.

Mr. Brendlinger.—You can build brick work for $10.

Mr. FitzGerald.—I don't think we have built it quite as cheaply as that in Boston, even by contract.

Mr. Brendlinger.—Those are contract prices. I know a contractor can do work faster and cheaper than an engineer.

There is one thing about getting in your track. You say in the first place they took down twelve rails, and put them in a wagon or car, and transported them to a certain point, and then put them on a cart, and they handled them thirteen times. Why was it necessary to handle them more than once?

Mr. FitzGerald.—There was a difference in sections; the tunnel was of an entirely different section from that in the aqueduct. This car was made to fit the invert of the aqueduct. The iron wheels were bound with oak tires, and that same car could not have been run through the tunnel.

Mr. Brendlinger.—The tunnel itself was not lined with brick work at the bottom?

Mr. FitzGerald.—No; the tunnel was of irregular section with a straight floor.

Mr. Brendlinger.—The handling includes everything, from the outside?

Mr. FitzGerald.—Everything.

Mr. Brendlinger.—It looked as though there was more handling than necessary.

Mr. FitzGerald.—It might appear so, but if you count every time a man handles a rail it counts up very fast.

Mr. Brendlinger.—In regard to the track, it struck me that there could be a better arrangement made. Of course, you have spent years on it, and I have just read the paper once.

It struck me that there must have been considerable resistance or interference with the flow of water, and there might be a different arrangement made.

Mr. FitzGerald.—We found in transporting the material, which was all pretty heavy and had to be carried very fast, that it was a great thing to have the track very rigid. The supports were directly under the rails.

In regard to the flow of water, there was plenty of room between the centers for a flow of 60 000 000 galls. per day, so there was ample space. The centers were all built without any bracing.

Mr. Brendlinger.—You supported the roof entirely from the centers?

Mr. FitzGerald.—Yes.

Mr. Brendlinger.—Was there much rock falling?

Mr. FitzGerald.—Not a great deal.

Mr. Brendlinger.—Judging from the speed you made, I thought you could not have much rock falling. Using dry filling would have reduced the cost to $8 a yard, instead of $16.

Mr. FitzGerald.—Oh, no; the ordinary distance from the top of the arch was only $2\frac{1}{2}$ ft., and, in places, less than that. I am sure it would have cost more to have stopped our concreting for this small amount of dry filling.

Mr. Brendlinger.—But I am suggesting that no concrete at all be used.

Mr. FitzGerald.—You mean brick work?

Mr. Brendlinger.—Brick work.

Mr. FitzGerald.—The only reason we took up the concrete was on account of the cheapness, but this is a matter on which men may well differ, and I wish to hear some reasons in favor of the brick work. Of course, if dry filling is used I can understand its effect in reducing cost, but would this have prevented farther disintegration?

Mr. Brendlinger.—In connection with this subject, I might say that in the repair of the Croton Aqueduct we used a similar construc-

tion. The wagons had 6-in. wooden wheels. The wagons would fill a barrel full, and each wagon held nine barrels of cement and sand mixed. Of course, there was a little injury done to the invert, but that was done by the mule shoes.

James Owen, M. Am. Soc. C. E.—How long after the concrete was set in place did you strike the centers? What period of rest did you give?

Mr. FitzGerald.—That varied with the convenience of the work. We had 75 centers and we kept moving them up from the end of the work. Sometimes they would stay in quite a long time; at others, not a week. I should say there was no trouble about taking them down a few days after the concrete had set. We did this work when we had an opportunity, in winter. We would put the men in and work them for four or five weeks or more on the work, and sometimes the centers were in quite a while before being struck; at other times we wanted the centers and we would take them down and use them.

Mr. Owen.—You did not find any trouble with water flowing through the roof?

Mr. FitzGerald.—No; because that was all carried down through the drains. The drains were a very essential part of the work; they were cheap affairs, simply made out of spruce boards.

William Barclay Parsons, M. Am. Soc. C. E.—I am very glad that Mr. FitzGerald has presented this paper to the Society. Engineers, at least in the eastern part of our country where there is a widely distributed abundance of good building stone, have not given enough attention to stone's humbler rivals—brick and concrete. Encouragement should, therefore, be given to every paper presenting the merits of either of the latter. For linings, such as Mr. FitzGerald describes, concrete is particularly well adapted.

A few months ago I had occasion to inspect professionally some of the large irrigation works in California and Arizona, and was much impressed by the successful, ingenious and bold manner in which concrete had been used for the lining of both canals and tunnels. Irrigation tunnels which resemble the tunnel described by Mr. FitzGerald are generally lined with concrete from 4 to 6 ins. thick, put in place by the aid of a track and a movable center.

One of the great advantages possessed by concrete as a lining for tunnels is that greater strength is obtained for the same thickness of ring than with brick. If the latter is used, the backing must be either of concrete or dry packing, which, being a separate material from the brick, adds nothing to its strength, so that the lining proper has to be strong enough to resist the whole pressure, and with brick the arching would have to be at least 8 ins. or two bricks thick. With concrete, however, the lining and backing form one homogeneous mass, so that in tunnels of small section it is safe, unless the material passed through

is of a very treacherous nature, to use a lining of a thickness of 4 or 6 ins., as compared with 8 ins. of brick, outside of projecting points of rock. In lining old tunnels, as in the Boston case, where it is undesirable to encroach on the sectional area, this is a great advantage.

Irrigation canals in California are also lined with concrete, which is put on in three ways: Either as a regular concrete, composed of broken stone or gravel; or else the bottom is roughly paved with smooth field stones to a depth of about 8 ins., a lime mortar being poured in to fill up the interstices and a strong Portland cement mortar flushed over the whole, the lining of the sides, generally about 4 ins. thick, being carried up from this foundation; or, thirdly, in some cases the sides and bottom are carefully trimmed and then covered over with a Portland cement plaster 1¾ to 2 ins. thick, which can be done only where there is no frost. This thin coating, when well laid, is permanent even on sandy or loamy banks.

Part II of the State Engineer's Report of California for 1888 gives an illustrated description, with cost, of several of these concrete linings.

Mr. Lesley.—In connection with what Mr. Parsons has said, drawing attention to the distinctions between brick and concrete lining for tunnels where trains are running through, without going into the actual cost, there are cases where large railroads are doing better in cost, or in practical results, by lining tunnels with concrete. One tunnel I have in mind is on the Philadelphia and Reading Railroad, at Perkasie, and another, the Musconetcong tunnel, on the Lehigh Valley, near Easton. The work was carried on very much as Mr. FitzGerald has carried on his. The arch in those tunnels had gradually come down with the water; I think in one there was 8 ins. of concrete; in the other, 6 ins. of concrete, the work being carried on continuously while the trains were running. These two tunnels were both lined with concrete, and have been in operation some two or three years.

Mr. Kenneth Allen, M. Am. Soc. C. E.—Some years ago, I believe, Mr. Chanute lined a number of culverts and arched bridges with Portland cement concrete. I think it was 6 ins. to 1 ft. thick, generally, and it stood very well.

Mr. FitzGerald.—If you will allow me a word, it seems to me the principal lesson to learn is, that if you are building a tunnel, it is cheaper and better to line it when you are building it than after it is in operation.

Mr. Brendlinger.—Referring to what Mr. Parsons has said, I cannot conceive how a concrete arch can be put in cheaper than a brick arch. Taking Mr. FitzGerald's report, it took him three seasons to do this work. I will warrant you that a good contractor will put that in in one season, with brick work.

There is another thing. Mr. FitzGerald says this cost $16 a yard,

his centers cost $1 400, and his shanties cost $1 200. A contractor would put that shanty up for $500; that is just the difference between an engineer doing the work and a contractor. If a contractor put in a brick arch—a good, conscientious contractor—he would do it for half the price.

Mr. Lesley made a statement about tunnel work; he does not produce figures at all; he does not say what the cost of a brick tunnel would have been in that place, so you cannot make comparison there.

O. F. Nichols, M. Am. Soc. C. E.—I want to say a word only in answer particularly to Mr. Brendlinger's remarks. A great deal depends on the manner in which work is done. Concrete has been used recently in many ways that were not dreamed of before and with great success. Good Portland cement gives us superior concrete for strength, equal almost to rock itself; but for best results it requires the utmost care, and a thorough and persistent inspection. I do not think there are many engineers who would entrust a piece of concrete work of this kind entirely to any contractor, no matter how good he might be. I have built a good deal of brick work, a great deal under contract and much by day's work. It is particularly difficult to make a good brick arch lining, even when you have the best conditions; the connections, and the binding at the key are difficult and there is some uncertainty about the action of the parts together when completed; it requires a great deal of care to get the joints properly filled and the work all right. I think the work in this case could certainly be done cheaper in concrete than in brick. The great advantage, it seems to me, is that you obtain a more certain homogeneity in material in concrete and with greater ease than in brick work. The price seems to be remarkably low; the work seems to have been done with the utmost care and attention and very economically, all things considered. The cost of this concrete lining could be compared more justly with concrete filling of pneumatic caisson than with concrete in open cutting, and such a comparison will show that the work was on the whole economically done. Of course, corporations like the city of Boston provide better shanties for their men than the average contractor does, even on the Croton Aqueduct.

Mr. FitzGerald.—I have had the pleasure of putting in a great many thousand yards of concrete in other places in the last two years, and that concrete generally costs between $5 50 and $7 a yard. It does seem rather a high price for Boston to pay for this concrete, $16 a yard; but take into consideration the circumstances, that you have got to provide the track, etc., etc., and then that the work cannot go on continuously, that it must be done at convenient times, and it must be done under exactly these conditions, that alters the whole thing. I was rather disappointed at the total cost of the concrete as a whole, but I believe the work was done as economically as

possible and very much better than a contractor could have done it. Of course a contractor can generally do work at lower prices than engineers, but I believe it would have cost a contractor nearly as much as $16 a yard. A contractor would not have been willing to have taken this work as it had to be done. He would have to hire his men, then discharge them again, and that would have added largely to the cost; it is like a contractor taking a piece of work that has not been tried, he would want a very large margin for contingencies.

JOHN BOGART, M. Am. Soc. C. E.—I do not care to add to the quite full discussion of this evening, except, perhaps, to allude to one interesting remark of Mr. FitzGerald, that a lesson to be learned was, that if you have a tunnel through rock which is at all dangerous, you had better line it at the start. In a very large tunnel in the western part of this State, with the construction of which I was connected, we had not gotten very far before the character of the rock developed in such a way as to require a determination as to the desirability of lining. Although this increased the expense very considerably, a heavy lining of brick was put in.

There was to be in this tunnel a very rapid flow of water, the inclination being great, so as to take a very large amount of water through it, and it was determined that a brick which should be pretty nearly vitrified, burned very hard, would probably give the best surface to resist abrasion that we could economically secure, and some interesting experiments that have since been made upon various substances with a sand blast by a member of this Society, with whom I was associated in this work, have shown that the resistance of a very hard-burned brick to abrasion is about the greatest that occurs with any substance which could ordinarily be used in lining such a tunnel. This was the tunnel at Niagara Falls, built by the Cataract Construction Company. I hope before long to be able to present data on this subject in greater detail.

MR. L. LUIGGI.*—A gentleman desires to know the amount of water that is to be used for making a good Portland cement concrete mixture. I have here a report of a good many experiments made during 10 years in the harbor works of Genoa, where about 350 000 cu. yds. of concrete in concrete blocks were required, besides 100 000 cu. yds. of concrete laid under water, or more than 500 000 cu. yds. of concrete. These experiments were carried out with the greatest possible care. There are tabulated here the results of experiments, using different dimensions of sand, different dimensions of pebbles, broken stone, etc., the influences of the amount of water and a large number of the possible contingencies that happen in ordinary work. The conclusion is, that in a mixture of which about 70% of the volume is sand, 30% is water.

Then another point, speaking about the porosity of the concrete;

* Engineer in charge of Harbor Works, Leghorn, Italy.

there are here a good many experiments on the porosity of mortars and concrete. Porosity of mortar and concrete depends first of all on the visible voids between the grains of sand and shell and broken stone. If you take a part of sand and mix it with water in a glass, and stir it, you will see a certain amount of air bubbling up. There is an amount of water that you can hardly get out of the sand which makes a void that has to be taken into consideration. Then there is another void that is the result of the evaporation of water. These different voids have been separately calculated by experiment and the total void estimated. They made some blocks of mortar and concrete, and thoroughly dried and weighed them, and then immersed them in water for periods of two weeks, one month, etc. They were then weighed again, and evidently the difference in weight is the water that went into the voids.

A mixture is given that has only 5 per cent. of voids. The conclusion as to the porosity of mortars is, that mortars made with cement and coarse sand are the least porous of all mortars; and the most porous of all is one made with cement and very fine sand, and especially a mortar of only cement is more porous than with sand.

This porosity is not to be confounded with permeability.

The conclusion is, that with the same amount of cement a mortar made with coarse sand is more permeable than one made with fine sand; it is just the opposite with the porosity. With the same amount of sand, if you put less cement, the permeability increases.

Mr. Lesley.—The gentleman has stated that in determining the porosity of a block, that a block of concrete was put into water and the absorption was noted; was there any allowance made for the chemical combination between the cement and water making the hydrated double silicate of lime and alumina? In other words, a briquette of cement put in water at seven days, say, will show that the chemical combustion is only partly effected, moisture will show all over the broken section. It will be found, after from three to six months, that a little dry core will be gradually formed. At the end of four or five years moisture will only go into a very little section, the rest being dry and crystalline. That indicates that there is a chemical combination between the lime and water, taking up so much of the water. If the amount of water that the blocks absorb only was calculated, it might not alone determine that that block was so porous. It would have to be determined what percentage of water the cement would take up to form hydrated silicates of lime and alumina. Unless that were calculated, merely saturating a block would not indicate anything accurate or definite.

Mr. Luiggi.—Those experiments were made by immersing the blocks in water or in sand which was kept constantly under water two or three years; then they were dried in a warm room.

A MEMBER.—What is the pamphlet in which these experiments are described?

Mr. LUIGGI.—It is the "*Giornale del Genio Civile*," the number for October, 1893. I should say it would be worth while in this country to continue these experiments, because it is easier to take them than to make them anew.

Mr. FITZGERALD.—There was one curious result noticed in mixing our sand and cement. If you take two casks of sand and one of cement and mix them, five times say, over and over again, they still fill the three casks, but the moment you put the water with them, the cement goes into the sand. It is almost impossible to mix the sand and cement together dry and reduce the bulk; the moment the water is added, the cement is driven into the voids of the sand, and of course the bulk is reduced.

JOS. P. FRIZELL, M. Am. Soc. C. E. (by letter).—The work of repairing the tunnel of the Sudbury Aqueduct, as detailed by Mr. FitzGerald, leaves little ground for criticism. The mixing of concrete in place I particularly approve of. Concrete cannot be transported and rehandled without sliding it, more or less, down inclines, which tends to separate it. The mortar sloughs down while the stones tend to roll, and the two materials usually land in different piles. A similar tendency to separation takes place when concrete rolls or slides down against a bulkhead or lagging. Concrete deposited against a flat surface, afterwards removed, is more likely to have cavities in the face than elsewhere in the mass of the work. A little consideration will show that this is unavoidable. Suppose concrete deposited on both sides of a thin plate. Every stone in contact with this plate bears against it at a single point. It could rarely happen that any two of these points are exactly opposite each other. On withdrawing the plate every stone will be free to advance a little, and will, on the whole, take a closer arrangement, which is the normal arrangement of the mass, and is, therefore, closer than the surface deposited against a wall.

In a work of this kind, when all operations are necessarily crowded, I could see no advantage in making two classes of concrete, one of American cement and one of Portland. The extra labor and loss of time incident to such an arrangement would more than counterbalance any saving in cost of cement.

From the leaving of the railroad track in place, making it, as it were, a permanent fixture of the tunnel, it is presumed that further falls of rock are apprehended. This suggests a question which Mr. FitzGerald's paper does not directly answer. If the falling had been allowed to go on and operations confined to the removal of débris from time to time, the fall of threatening portions being facilitated, what disaster was to be expected? Would this mode of dealing with the difficulty have brought the safety and permanence of the tunnel, as a

conduit, into question? As this question appears to have been decided in the affirmative, I infer that the rock was of a character liable to complete disintegration on exposure to the atmosphere.

Conceding that these repairs were carefully planned and skillfully executed, it is not to be forgotten that the construction of a tunnel which gives no occasion for repairs is a still better piece of engineering. In the excavation of a tunnel rocks will usually be disclosed whose characteristics are not familiar to the engineer. Some rocks, chiefly limestones, grow harder on exposure to the atmosphere. Some rocks crack, disintegrate and go to pieces under the same influence. No engineer can be presumed to have the geological and chemical skill to determine on inspection of a rock what will be its behavior on exposure. Nevertheless, this proposition, I think, cannot be disputed. A tendency on the part of a rock to disintegration can readily be detected by observing it for a few months under atmospheric influence, especially the action of frost. Samples of every variety of rock, whose weathering qualities are not familiar to the engineer, should be preserved in exposed situations and their behavior noted. On information so obtained, more confidently than on learned opinions of chemists and geologists, the engineer can determine the portions of the tunnel requiring to be lined.

Another point in the construction of conduit tunnels may be adverted to in this connection. In a lined tunnel considerable spaces often exist above the arch, which are usually filled solid with masonry, or, at least, supposed to be. This is required for two reasons: 1, to secure the arch against being lifted or burst up by internal pressure; 2, to avoid injury to the arch from falling rock. In a tunnel like the one in question, forming part of a gravity conduit with unbroken grade, the first consideration has no force. As to the second, the filling of these chambers with gravel or quarry spawls would be just as effective, large fragments being excluded. The first reason has a seeming application to a tunnel working under pressure, as a tunnel under the bed of a river, but even in that case its force is more apparent than real. Its only application is to the first filling of the tunnel, or to the very improbable case of its being pumped out. If the arch is tight, the natural seepage will insure the full external pressure on it at all times. I am told that the disused Washington tunnel discharges 1 000 000 galls. a day from natural seepage. If the arch is not tight, the filling of the tunnel will fill the spaces above the arch, and so equalize the pressure. The tunnel and lining can readily be arranged to secure this result. Experience at the Washington and New York tunnels shows how difficult it is to get these spaces filled with masonry. This part of the work is regarded as a legitimate subject of fraud, because the contractors and inspectors do not consider it essential. There would be no difficulty in getting these spaces filled with spawls

from the excavation, because that would be the easiest way of disposing of this material. The side walls should, of course, be carried up solid to the spring line of the arch. There would be no opportunity for fraud in this part of the work. A deficiency of 6 ins. or 1 ft. in the filling, which could not occur anywhere but at the top, would do harm, as a stone detaching itself from the roof and falling that distance upon a bed of loose material would bring no shock upon the arch.

On the other hand, the fraudulent execution of this work, as such frauds are usually practiced, viz., by running up bulkheads at intervals of 15 or 20 ft., leaving vacant chambers between, exposes the arch in these chambers to both forms of injury referred to, so far as the first is possible anywhere.

Foster Crowell, M. Am. Soc. C. E. (by letter).—Having been present at the meeting when this paper was discussed, but called away before having opportunity to speak, I desire to comment briefly on the paper, and particularly with regard to the point brought out in the discussion as to comparative cost of what have been designated as "contractor's" and "engineer's" work.

I cannot agree with some of the speakers either as to facts or conclusions. Mr. Brendlinger is correct in stating that brick work can be built for $8 per cubic yard, not taking any other values into account, but my experience does not justify me in supposing that any contractor would undertake to line an aqueduct of the dimensions given and in service for any such price. If Mr. FitzGerald were to itemize his figures and separate the extraordinary and unique portions of expense from the cost of the masonry, the concrete would be found to average about $14 per yard, for material and labor, and I doubt much whether my friend, Mr. Brendlinger, who is high authority on this topic, being always an excellent engineer, though sometimes a contractor, would undertake to do the work in the manner Mr. FitzGerald has described for much less, although the opportunity of selecting his own men would give him a great advantage over the officials of a municipal organization.

The reference to the Croton Aqueduct fails to add weight to the argument, excepting so far as it points to the difference in value between contractor's work and engineer's work. It is said that some contractors discovered just what that value was when they came subsequently to build the "difference."

It appears from the report of the Croton Aqueduct Commissioners of January, 1887, that the average contract price, on Sections 2 to 4, inclusive, of the new aqueduct (extending over 30 miles), for brick masonry lining made with Portland cement, was $12 37 per cubic yard; on three sections it was $13 50. Here the tunnel dimensions and volume of the work were much greater than in the work under discussion, and all the conditions vastly more favorable.

I would point out, also, that other things being the same, the application of concrete, from its nature, should be better and cheaper in a case of this kind than brick work, and the unavoidable inference is that, had brick work been used, the cost would have been greater. The cost of the various items, outside of the lining proper, was, doubtless, very much enhanced by reason of the local obstacles; for instance, the minor item of track appears to have amounted to about $1 for each cubic yard of concrete; this track was carefully and laboriously built, first distributing the rails along the entire length instead of delivering them from one end over the advancing track. The necessity of keeping the aqueduct in service was probably an adequate cause for this. I am inclined, from my own experience, to believe that a careful contractor would have declined to take this work, except on a labor and percentage basis, and that the result would have been no more favorable as to cost than Mr. FitzGerald obtained; while, without meaning to reflect on contractors, there would have been no such assurance of permanency as now appears. In regard to Mr. FitzGerald's experiments on proportions of ingredients of concrete, which he alludes to and which, I trust, he will give us the benefit of hereafter, I would point out, as I have already done in some previous discussions, that the question of proportion is one that can be best met by special gaugings with the material at hand; the size, porosity, fracture of the stone; the degree of fineness, shape and quality of the sand; the fineness and quality of the cement, even the chemical constitution of the water used, all come in. All contributions throwing light on these points are useful, but the physical characteristics of the materials must be given to make the experiments really valuable. In every case the voids in the stone, the voids in the sand, and the voids and chemical capacity for water of the cement, should be carefully measured; likewise the experiments should run through several proportions and kinds of water. Too much cement will weaken concrete just as too much glue weakens a cabinet-maker's joint. The proper fineness of the sand is of scarcely more importance than the shape of the grains, round grains giving maximum voids, minimum surface and greatest leverage on the cement, while a sharp sand reverses these conditions. Tests must be on the concrete and not on the cement.

James Duane, M. Am. Soc. C. E. (by letter).—There are a few points not fully brought out in Mr. FitzGerald's interesting paper and on which additional information seems desirable. *First.*—In view of the geological formation as described, why was not the tunnel lined as a part of the original construction; when, of course, the work could have been done to much better advantage, and there would have been less of it to do. *Second.*—While the author refers to the use of American cement concrete, and the table shows that 486 bbls. of American cement were used in the work, no description of the method of

making such concrete proportions of the different ingredients nor of the cost per cubic yard are given. It would be interesting if Mr. FitzGerald would kindly furnish this data. While employed as Superintendent of Construction in the 2d Light House District (coast of Massachusetts) some years ago, I constructed a number of heavy concrete foundations. Some of these were of Portland facing, Rosedale backing. In the light of the experience then gained I must agree with Mr. FitzGerald that the economy resulting from such composite construction was problematical, to say the least. As he well says, when you have a concrete gang well organized and everything working smoothly in all its details, a stoppage in any part disarranges the whole system. We soon found that it was generally more economical to increase the amount of ballast in our Portland cement concrete than to use Rosendale at all under ordinary conditions while the work went on harmoniously without any hitch. Another distinct advantage gained was in having a uniform binding material throughout the entire mass, thus securing uniformity in the time and method of setting, or of contraction, expansion, etc. It is believed that a more homogeneous structure was thereby obtained. It may be added that the difference of cost of the two kinds of cement was less to us than it would have been to an ordinary corporation, as the Government received its Portland cement duty free.

P. D. Ford, M. Am. Soc. C. E. (by letter).—In the discussion of the paper on "Lining a Water-Works Tunnel with Concrete," by Mr. FitzGerald, on the evening of February 7th, the lining of Perkasie Tunnel on the North Pennsylvania Division of the Philadelphia and Reading Railroad was mentioned.

In looking up some old memoranda on the subject made during the progress of the work, I find the following items which may be of interest in connection with the discussion of the paper of Mr. FitzGerald.

Perkasie Tunnel has a length of 2 117 ft., through a firm, compact rock, intersected transversely to the tunnel by several nearly vertical strata of rock of a seamy nature, varying in width from 20 to 125 ft.

From the time the first trouble was experienced from the falling of rock from these sections upon the floor of the tunnel, a gang of men was sent at regular intervals through the tunnel, making a careful examination and detaching every piece of loose rock and every piece of rock they could loosen. Notwithstanding this, the rock continued to loosen from natural causes, and the company determined to line one of the seamy sections with a béton of Portland cement, sand and fine gravel as an experiment. The most troublesome section, 125 ft. in length, was thus lined, before my connection with the road, in the year 1886, I think.

This proving a success, the lining of the remaining troublesome sections was undertaken in the fall of the year 1888. The inside di-

mensions of the lined portions of the tunnel were as follows: Vertical side walls from floor to springing lines, 14 ft.; chord between springing lines of intrados, 26 ft. 2 ins.; rise, 10 ft. 7 ins. The arch at key had a minimum thickness of 18 ins., and the side walls 12 ins.

Instead of using béton, as in the first section lined, the remaining sections were lined with a concrete composed of 1 part of Heyn's German Portland cement, 2 parts clean, sharp sand, and 3½ parts of broken stone.

At the time the lining was done there was a single track laid on center line of tunnel, and in service. Traffic was unimpeded during the progress of the work. Four sections were lined, varying from 20 to 75 ft. in length. The work of furnishing, erecting and removing the centers was done by the railroad company. The concrete was furnished and laid by contract.

Void spaces of any considerable size above the extrados of the arch were partially filled with dry-stone work, forming a cushion on the arch about 3 ft. thick. Smaller spaces, say, up to 18 or 20 ins., were filled up solid with concrete.

The side walls and haunches of the arch were entirely of concrete. The extrados was inverted over the haunches, forming gutters which led to weep holes having iron pipes built in them, the pipes extending some 2 or 3 ins. inside the intrados for conveying water to the drainage ditches of the tunnel.

The dry filling was laid by the railroad company. The concrete was mixed on the surface of the ground, 34 ft. above crown of arch, and conveyed to the tunnel through a shaft from the bottom of which it was wheeled to the various sections.

The total amount of concrete laid in 164 ft. of arching above springing line, and 114 ft. of side walls, was 13 609 cu. ft., at 40 cents per cubic foot. I am unable to furnish the actual figures of cost of centering in place, but the total cost of the work, exclusive of dry filling, was estimated to amount to about 50 cents per cubic foot of concrete laid.

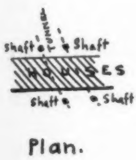
E. Sherman Gould, M. Am. Soc. C. E. (by letter).—A very useful paper, giving minute details of the execution of a very difficult undertaking. From its nature it does not afford much room for discussion, because no one would venture to criticise the methods employed without having a personal knowledge of the ground and the various conditions of the problem. Perhaps its most useful lesson is in showing the advisability of lining all aqueduct tunnels at once, before laying on the water, because they are pretty sure to need lining sooner or later.

Some interesting facts are incidentally brought out. The moot point of how many cubic feet go to a barrel (or "cask" as Mr. FitzGerald calls it) of cement is settled by the statement that two barrels measure 6.84 cu. ft. Hence, we may take the barrel as cubing 3.40

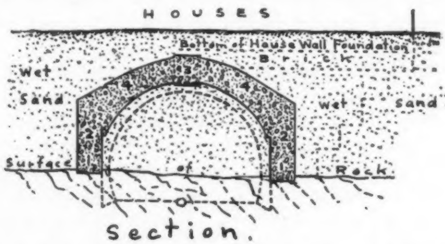
ft., for round numbers. I have recently been counting 10 barrels to the cubic meter, which agrees pretty well with the above.

Mr. FitzGerald states that the concrete was of exceptionally good quality. One would hardly have expected this from the manner in which it was mixed. I hope this point may elicit comment from other members, because if extra good concrete can be made in this way, then many of us have all along been taking a good deal of unnecessary trouble to accomplish the same result. As far as I have been able to figure it out from the data given, about 2½ cu. yds. of concrete were put into the work per day per man, all told, which is a high average.

E. E. R. Tratman, Assoc. M. Am. Soc. C. E. (by letter).—In a recent number of the *Proceedings* of the Institution of Civil Engineers (Vol. CXV, 1893–94, Part IV), is an account of a difficult piece of concrete underpinning on the Glasgow Underground Railway, a note of which may be of interest in connection with the projects for underground railways in New York. The tunnel was to pass close under a row of houses built on a stratum of fine sand saturated with water, overlaying a rock bottom. Four shafts were sunk to the rock, one at each end of each wall of the tunnel, as shown on the plan. Then the bottom headings



Plan.



Section.

(1) were driven and filled with concrete, and above these the headings (2), the upper surface of the concrete in these being sloped to form a springing. A crown heading (3) was then driven, and from this were built concrete ribs (4) until the two sides of the arch were continuous from end to end, after which the crown heading was packed with concrete. Under the house walls, wings of concrete were built and capped with brick built up tightly against the bottom of the foundation, as shown on the right of the section. When the concrete had set, the interior core was excavated and a brick lining built to the form shown by the heavy dotted line. The results were entirely satisfactory. It may be noted that this work was done by contract.

T. Kennard Thomson, Assoc. M. Am. Soc. C. E.—Would not an ordinary backing of earth or gravel have been good enough and much cheaper where the cavity was large ?

Additional information having been asked about the actual amount

of material required to make 1 cu. yd. of concrete, I would say that I had charge of some bridge foundations a few years ago, where the contractor used 1 cu. yd. of stone broken to pass a 3-in. ring; ½ cu. yd. of sand and ¼ cu. yd. of Rosendale cement to make 1.2 cu. yds. of concrete.

J. J. R. Croes, M. Am. Soc. C. E.—I understood one of the speakers to say that in the paper under discussion there was the first attempt that he had seen to give the exact proportions of stone, sand and cement in concrete. In Vol. III of the *Transactions* of the Society, published in 1874, there is a very full and detailed analysis of the proportions of sand and cement and stone, and also water, used in making the concrete for the Storage Reservoir Dam of the Croton Aqueduct Department at Boyd's Corners, N. Y., and a comparison of the same with concrete made for a reservoir of the St. Louis, Mo., Water Works, and a summary of the conclusions reached by the writer as to the best proportions of the materials for concrete.

Mr. FitzGerald.—In closing this discussion I desire to express my appreciation of the attention which this little paper has received. I feared that it would prove stupid, and should certainly never have read it had it not been for Mr. Brush. It shows that any work of which a careful record is kept may prove of interest to the profession.

There are several questions remaining to be answered. In regard to the relative cost of brick work and concrete it is safe to say that in Boston brick work costs double as much as concrete.

The ordinary price used in estimating on common work, as, for instance, in sewer work, where hard-burned bricks are used, is $12 per cubic yard for brick work laid in American cement mortar, and $14 if laid in Portland cement. It does not cost quite as much, for this includes the contractor's profit. In a piece of work recently constructed under contract, vigorously pushed and well handled, and containing 1 328 cu. yds., the cost, as ascertained by most careful force accounts, was as follows :

	Cost of brick work per cubic yard.
Labor	$2 89
Bricks	5 49
Sand	0 30
American cement	1 35
Centers	0 23
Miscellaneous	0 19
Total	$10 45

In this piece of work, selected from many others on account of its

general accuracy, 1.27 casks of cement were laid in each cubic yard of brick work. In Boston, Portland cement costs about $1 27 more per cask than American cement, the prices being $2 40, and $1 13 delivered.

In one cubic yard of brick work laid in cement there are from 560 to 580 bricks, without allowance for breakages, etc., and the cost delivered will average, say, $9 50 per 1 000. From the average of a number of force accounts it has been found that the labor costs $3 40 per cubic yard. We can now make another schedule as follows:

	Cost of brick work per cubic yard.
Labor	$3 40
Bricks	5 30
Cement	1 50
Sand	40
Centers	20
Miscellaneous	20
Total	$11 00

Where no large collar joints are present it is usual to reckon 1.23 casks of American cement to one cubic yard of brick work. If we use $11 for American cement brick work, we must use $12 50 * for same laid in Portland cement.

With the above figures I think it will be possible for any engineer to form his own opinion as to whether brick work would have been cheaper than concrete for the lining of the tunnel.

Mr. Crowell, I think, has shown very well that brick work in New York in tunnel has cost about $13 in large quantities, and under circumstances vastly more favorable than with an aqueduct in service.

To reassure Mr. Gould, I will repeat that the concrete turned out to be of most excellent quality. Mr. Gould's figures in regard to the quantity of concrete laid per man per day, however, need revising. I make it about 0.45 cu. yd. laid per man per day, instead of 2.5 cu. yds.

Mr. Duane asks as to the cost of the American cement concrete. This was used in the same proportions and cost $1 84 less per cubic yard, or $14 31. The usual prices in Boston are $6 and $8 per cubic yard for American and Portland cement, respectively. The reason the tunnel was not lined when first constructed was that, after consultation

* Generally $13, on account of its being a higher class of work, thinner sections, larger collar joints, etc.

with an expert geologist, it was thought unnecessary. This, I think, answers Mr. Duane's first question.

Mr. Frizell wishes to know what harm would have resulted from leaving the roof to fall, and my answer to this is, that aside from final stability of the roof, the falling rock might have killed some one, either during inspection or while cleaning the aqueduct. We clean twice a year.

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SPIRALS AND THEIR USE ON RAILROADS.

By A. S. C. Würtele, M. Am. Soc. C. E.

Read March 2d, 1894.

The constantly increasing rate of speed at which railroad trains are now run calls for a corresponding increase of care on the part of the constructing engineer in laying out and improving lines of railroad.

It is no longer sufficient simply to counteract the centrifugal force on curves by elevating the outer rail according to the well-known rules. This was well enough for a speed of, say, 30 miles per hour, but now we look forward to a speed of 100 miles per hour, and the smooth running of a train at such speed requires a more complete system of rail elevation than has been in use, for the reason that at the point of curve the rail cannot be raised suddenly to its proper elevation, but only gradually, so that, at entry on a curve, a shock occurs from lack of compensation for the centrifugal force suddenly developed. To obviate this shock, systems of spirals at the commencement of curves have been adopted and are now being used, so that, from the gradually diminishing radius of curvature of the spiral, the outer rail can now be put at its proper elevation from the very point of a curve.

Twenty-five years ago, on location, the writer compounded all sharp curves by putting in 100 ft. of a 1° curve at each end, and no doubt with good result for those early days of the development of the railroad system as it now exists.

In Great Britain, Mr. Gravatt, about 1829, advocated the use of the curve of sines instead of the circular curve, and about 1842 W. Froude invented the "curve of adjustment," to be used at each end of a circular curve. The length of this curve of adjustment was 300 times the proper elevation of the outer rail for greatest speed. The circular curve was set in towards the center by a small distance, found by dividing the square of the above length by 24 times the radius. One-half the length was set off each way from the point of curve, and the curve of adjustment was finally set out by offsets from the curve as set in towards the center, the offsets being proportional to the cubes of distances from the ends, the cube of half the length, and half the distance set in.

In all flattening of ends of curves the main curve must necessarily be slightly sharpened, and this is effected by setting the curve in towards the center.

Wellington in 1881 and Searles in 1890 have dealt exhaustively with the subject of railroad spirals;* but as the thing has not been practically used in general, and is probably little studied or understood by many working engineers, the writer is emboldened to present the following general view of spirals, and to add a system he has worked out for the use of a single spiral, uniform for all curves, by using different lengths of spiral, as indicated in the accompanying table.

The Spiral Generally.—The equations of spirals are of two forms—1st, the radius vector a function of the angle turned in circular measure, and, 2d, the perpendicular on the tangent from the pole a function of the radius vector: so that there are an infinite number of spirals, of which some of the best known are indicated.

One large family of spirals has the equation $r = a\,\theta^n$, in which every change of n gives a different spiral.

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* Spiral Literature:

1881. Wellington in *Railroad Gazette.*
1884. Man in *Transactions*, Am. Soc. C. E.
1890. Searles in book form.
1891. Gribble " "
1892. Caine in *Transactions*, Am. Soc. C. E.
1892. Ward " "
1893. Crandall in book form.

$n = 1$ gives $r = a\,\theta$ or $p = \dfrac{r^2}{\sqrt{a^2 + r^2}}$ the spiral of Archimedes;

$n = 2$ gives $r = a\,\theta^2$ the parabolic spiral;

$n = -1$ gives $r = \dfrac{a}{\theta}$ or $p = \dfrac{a\,r}{\sqrt{a^2 + r^2}}$ the hyperbolic spiral;

$n = -\frac{1}{2}$ gives $r = \dfrac{a}{\theta^{\frac{1}{2}}}$ the lituous spiral;

$n = \frac{1}{2}$ gives $r = a\,\theta^{\frac{1}{2}}$

which may be called the railroad spiral, as it has properties rendering it easy to use, and it gives good results. Some of these properties are as follows: The angle of the tangent with the radius vector is double the angle of the radius vector with the origin line; the total angle turned to any radius of curvature is equal to the angle turned in a curve of the same radius in a distance equal to half the radius vector; the distance the spiral will fall inside the curve is one-fourth the ordinate at the end of the spiral.

The helicoidal parabolic spiral has the equation $(a - r)^2 = 2\,a\,b\,\theta$. The logarithmic spiral is given by $r = a^\theta$ or log. $r = \theta$; this is also called the equiangular spiral as the angle between the tangent and the radius vector is constant. Had the force of gravity varied as the cube of their distance, the planets would have continually receded from the sun in a logarithmic spiral, as shown by Newton.

Cotes' spirals are of interest as being the orbits in which bodies, projected with different velocities in different directions, would be held by an attracting force inversely as the cubes of the distances.

The equations are $p = \dfrac{b\,r}{\sqrt{a^2 + r^2}}$

$b = a$ gives a log. spiral, and $p = \dfrac{b\,r}{a}$ gives $\theta = \dfrac{b}{\sqrt{a^2 - b^2}}\log.\dfrac{r}{a}$

$a < b$ gives $\theta = \dfrac{b}{c}\log.\left(\dfrac{\sqrt{a^2 + c^2} - c}{r}\right)$ where $c = \sqrt{a^2 - b^2}$

$a > b$ gives $\theta = \dfrac{b}{c}\sec.^{-1}\dfrac{r}{c}$, or $r = c\sec.\dfrac{c\,\theta}{b}$ where $c = \sqrt{b^2 - a^2}$

Differential Equations.—The general differential equations necessary in solving spiral calculations are:

$$\frac{d\,A}{d\,\theta} = \frac{r^2}{2}. \qquad \frac{d\,s}{d\,\theta} = \sqrt{r^2 + \frac{d\,r^2}{d\theta^2}}$$

$$\frac{ds}{dr} = \frac{r}{\sqrt{r^2 - p^2}} \qquad \frac{d\,r}{dp} = \frac{R}{r} \qquad \frac{d\,\theta}{d\,r} = \frac{p}{r\sqrt{r^2 - p^2}} = \frac{t}{r^2}$$

$$\frac{1}{p^2} = \frac{1}{r^2} + \frac{1}{r^4}\,\frac{d\,r^2}{d\,\theta^2}$$

In all the preceding formulas, r is the radius vector, θ is the circular measure turned by r, p is the perpendicular from the pole on the tangent, s is the length of arc from the pole, t is the subtangent from the pole to the tangent and at right angles to r, A is the area between the radius vector and spiral.

From the given equation of a spiral the differentials are easily obtained; and, by insertion in the differential equations, and by integration between desired limits, the spiral is reduced in all its conditions.

The spiral $r = a\,\theta^{\frac{1}{2}}$ is reduced as follows:

$$\theta = \frac{r^2}{a^2},\ p = \frac{2\,r^3}{\sqrt{4\,r^4 + a^4}},= \frac{2\,r^3}{a^2} \text{ nearly;}$$

r^4 being very small compared to a^4.

$$R = \frac{(4\,r^4 + a^4)^{\frac{3}{2}}}{6\,r\,a^4 + 40\,r^5} = \frac{a^2 + 3\,a}{6\,r} \text{ nearly;}$$

$$\text{Sin. } \beta = \frac{p}{r} = 2\,\theta = \frac{2\,r^2}{a^2} \text{ nearly;}$$

$$x = \frac{r^3}{a^2} = r \sin.\,\theta = \frac{a^4}{216\,R^2} \text{ nearly; } d = \frac{x}{4}.$$

$$A = \frac{a^2}{2} \times \frac{\theta^2}{2} \qquad A = \frac{r^4}{4\,a^2}$$

Where R is the radius of curvature at the end of r, x is the ordinate at the end of r, d is the distance the end of r falls inside the circular curve, β is the angle between the tangent and r, x is proportional to the cube of r.

Determination of a.—Take a 3° curve, and, at 100 ft. on the curve, a radius vector from 50 ft. back of the point of curve will give the tangent to the spiral and to the 3° curve parallel, as $I = 3\,\theta = 2\,v$, I being angle of intersection and v deflection angle. From this $a = \frac{r}{\theta^{\frac{1}{2}}} = \frac{150}{(.0175)^{\frac{1}{2}}}$ $= 1134$, where .0175 is circular measure for 1°.

The tangents are now parallel, but the radius of curvature of the spiral is not equal to the radius of the 3° curve, but

$$r = \frac{a^2 + 3n}{6\,R} = 112.2.$$

When the radius of curvature of the spiral is 1 910, the same as the curve taken, and $\theta = \frac{r^2}{a^2} = .00979$, which multiplied by 57.296° reduces the circular measure to 33′.5, and consequently $\beta = 67'$, or the total angle turned is 101′. Now this angle will be turned by the 3° curve in 56.1 ft., or half of r, so that, starting the spiral 56.1 ft.

back from the point of the curve, and running $r = 112.2$, at angle of 33′.5 the tangents will be parallel and the radius of curvature of the spiral at the end of r the same as radius of 3° curve. But the points will not be together, the spiral falling inside the 3° curve by the amount $d = \frac{r^3}{4a^2} = 0'.27$, and by setting in the curve by 0.27, a complete curve will be formed in continuation of the spiral.

The table of the spiral $r = a\,\theta$, calculated for every 20 ft. of r, with a equal to 1 134, as above deduced, is suitable for railroad curves from 2° to 6°, and it can be set out by the offsets x with r; or by transit angles $\Theta°$ with r, when angle β gives the means of turning on the tangent at the end of the spiral.

The second table fixes the length of spiral for the curves it includes, and is to be used with the first table, which indicates the end of the spiral as well as the commencement at — $P\ C$, back from point of curve, also the final offset x, and distance $\frac{x}{4}$, for setting in the main curve.

Very sharp curves, as for street railways, of 40 to 100 feet radius, require correspondingly short spirals; and the third and the fourth table of spiral $r = a^{\theta \frac{1}{2}}$, calculated for every 5 ft. of r, with a equal to 58.1, obtained in a similar manner to the above, is suitable for curves from 30 to 60 ft. radius.

In case the offset of curve is fixed or another offset desired than as given in the table, the proper a for the required spiral will be had from the equation $d = \frac{a^4}{4 \times 216\, R^3}$, and r from $r = \frac{a^2 + 3\,a}{6\,R}$; when the angles for any length of r can be had from the general equation $\theta = \frac{r^2}{a^2}$ and the offsets x by $x = r$ sin. θ, or by $x = \frac{r^3}{a^2}$ and the spiral begins at $\frac{r}{2}$ from point of curve.

The above reductions have been made from the approximate equations of p and R, which are sufficiently correct for all practical purposes in the part of spiral used.

There is, of course, nothing new in the mathematical reductions of spirals, but only in their application to practical purposes. The writer consulted principally Hall's "Integral Calculus," "Encyclopædia Brittanica," and Davies & Peck, and has endeavored to collect together some widely scattered information on the subject of spirals, and to indicate the practical application of the same.

Spiral for Railroad Curves.

I.— $r = a\,\theta^{\frac{1}{2}}$ $a = 1\,134$

r	$\theta°$	$\beta°$	x ft.	y ft.	R ft.
20	1′.07	2′.14	.006	20	10 714.3
40	4′.28	8′.56	.05	40	5 357.2
60	9′.63	19′.26	.16	60	3 574.8
80	17′.11	34′.22	.40	80	2 678.6
100	26′.74	53′.48	.78	100	2 142.8
120	38′.50	1° 17′.00	1.34	120	1 787.4
140	52′.41	1° 40′.82	2.13	140	1 530.6
160	1° 8′.43	2° 16′.86	3.18	160	1 339.3
180	1° 26′.63	2° 53′.26	4.54	180	1 191.1
200	1° 47′.00	3° 34′.00	6.22	199.9	1 071.4

II.—

r	θ	β	x ft.	y ft.	R ft.	c	d ft.	—PC ft.
74.8	15′.0	30′.	.33	74.8	2 865	2°	.09	37.4
93.5	23′.4	46′.8	.64	93.5	2 292	3° 30′	.16	46.7
112.2	33′.5	1° 7′.0	1.09	112.2	1 910	3°	.27	56.1
130.9	45′.8	1° 31′.6	1.74	130.9	1 637	3° 30′	.44	65.5
149.6	59′.8	1° 59′.6	2.60	149.6	1 433	4°	.65	74.8
168.3	1° 15′.7	2° 31′.4	3.66	168.3	1 274	4° 30′	.92	84.1
187.0	1° 33′.5	3° 7′.0	5.09	187.0	1 146	5°	1.27	93.5
224.9	2° 14′.8	4° 29′.6	8.82	224.7	955	6°	2.21	112.5

Spiral for Street Railway.

III.— $r = a\,\theta^{\frac{1}{2}}$ $a = 58.1.$

r	$\theta°$	$\beta°$	x ft.	y ft.	R ft.
5	25′	50′	.04	5.00	118.3
10	1° 42′	3° 24′	.30	10.00	59.1
15	3° 49′	7° 38′	1.00	14.97	39.4
20	6° 47′	13° 34′	2.36	19.86	29.6
25	10° 37′	21° 14′	4.61	24.57	23.7
30	15° 17′	30° 34′	7.91	28.94	19.7

IV.—

r	$\theta°$	$\beta°$	x ft.	y ft.	R ft.	d ft.	—PC ft.
8.46	1° 13′	2° 26′	.18	8.45	70	.045	4.23
9.86	1° 39′	3° 18′	.28	9.84	60	.07	4.93
11.84	2° 22′	4° 44′	.48	11.82	50	.12	5.92
13.14	2° 56′	5° 52′	.67	13.13	45	.17	6.57
14.78	3° 43′	7° 26′	.96	14.76	40	.24	7.39
16.90	4° 51′	9° 42′	1.43	16.84	35	.36	8.45
19.72	6° 36′	13° 12′	2.27	19.59	30	.57	9.86
23.66	9° 30′	19° 00′	3.90	23.34	25	.975	11.83

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THE ELECTRIC STATION OF THE CITIZENS' LIGHT AND POWER COMPANY OF ROCHESTER, N. Y.

By ROBERT CARTWRIGHT, M. Am. Soc. C. E.

READ MARCH 7TH, 1894.

WITH DISCUSSION.

The inventions and improvements in electrical science at the present day are so rapid and comprehensive that a very little time makes great changes in the development of the machinery and the application of electricity to many new channels of industry. Already has the small steam engine been relegated to "innocuous desuetude" by this unknown but potent agent, because of the readier application, cleanliness and economy of the latter. The day cannot be long delayed in this progressive age when the generation of electricity by hydraulic power and its conservation in a transportable form will effect a revolution in many of its present objectionable features, and we will see the expensive copper wire at least restricted in its use, if not entirely displaced by storage, in a practical and economical manner. Do we not have energy of almost infinite capacity concentrated in the form of gunpowder, dynamite, nitro-glycerine and many other kindred compounds, and is it expecting too much of the inventive genius of this in-

ventive age to confine this subtle power, so that we can release and utilize it at will? " 'Tis a consummation devoutly to be wished " that some Edison or Tesla, some Thomson or Julien, will produce it from the combustion of coal, without the intervention of engine or boiler, water-wheel or dynamo, as an intermediate part of the plant. What electricity is, we know not. Its effects and its affinities comprise the sum total of our knowledge. Its development, instead of being the result of studied theoretical laws, is almost entirely experimental. The telephone and phonograph, the dynamo and transformer, are all the products of experimental research. Their inventors did not know what they sought, until, like Pandora opening her box, they released a series of perfected, though previously unknown, results.

The consolidation of the three gas companies and the three electric companies of Rochester, N. Y., into one organization, known as the Rochester Gas and Electric Company, was effected in 1892. This combination seems to have awakened in the mind of some of Rochester's citizens the old saying that "competition is the soul of trade," and hence the birth of the Citizens' Light and Power Company. Some of the stockholders in the different companies sold out their interests when the consolidation was entered into, and organized an independent company, whose plant, designed and constructed by the writer, is in operation, supplying electricity for light and power. Its equipment is of the latest and most improved machinery under the Westinghouse system. As the work embraces some interesting features, a description of the power plant in detail is furnished.

The city of Rochester, N. Y., is almost evenly divided by the Genesee River running through it from south to north, and having within the corporate limits of the city a total fall of about 257 ft., in a succession of three falls and rapids. The water is used over four times before it reaches the level of Lake Ontario. In former years when the drainage area of the country supplying the Genesee with water was covered with forests, the flow was constant and reliable, but to-day an advanced civilization has cleared off the land, and the consequence is that a dependence on the river, as a means of supplying power, is very irregular and uncertain, almost realizing the old adage of "a feast to-day and a famine to-morrow." This has become so unsatisfactory that the city's interests are jeopardized by it, and measures are now being taken to store the water, at a point near Mount Morris,

by damming it back in the ravine to the south. A bill is now being considered in the State Legislature, looking to this end. As the State of New York has the first right to the water of the Genesee, or so much thereof as is needed for feeding the Erie Canal, at times of drought in the summer the volume reaching the city is sometimes only 4 000 cu. ft. per minute, as per the gauging records of E. Kuichling, M. Am. Soc. C. E., and Chief Engineer of the water works. This, divided among the many industries dependent upon it, becomes practically useless. By impounding the water, as stated, the amount confined from melting snows and heavy rains would be dispensed at Rochester, so that a constant power of 30 000 H. P. per day would be realized, instead of passing through the city at times of freshets entirely unused.

In the opinion of the writer there is no other public improvement that will inure to the benefit of Rochester so much as the storage of the water of the Genesee. Parks and boulevards may easily wait until the utilization and application of all of the water of the river will so enhance the position of Rochester, as a city of reliable and cheap water power, that manufacturing capital will find a desirable investment in it, and fill the entire ravine below the falls with hives of industry which in a very short time would enable the city to adorn itself without the imposition of onerous taxation.

The fact of water storage in the near future being a possibility has been considered by the writer in designing the power station, so that advantage may be taken of it, when realized, without unnecessary change or expense. By reference to the accompanying plates, the location, disposition and construction of the work will be readily understood.

In August, 1892, the Citizens' Light and Power Company acquired the property now occupied by its station on Brown's Race, at the foot of Factory Street. Nothing but a mass of ruined walls and débris gave evidence of its having been previously occupied. The site was that where once stood the Jefferson and Clinton Flouring Mills, which were destroyed by fire under such peculiar circumstances that the writer may be pardoned for a narration of them.

Fig. 1 shows a plan and sectional elevation of the property at the time of its purchase by the Citizens' Light and Power Company. As will be seen, a main sewer traverses the whole length

of the Jefferson lot from Mill Street to the Genesee River. The sewer was 6 x 6 ft. in size, and was cut under Brown's Race by tunnelling the rock some 20 ft. below the race bottom, the lower portion built on the rock slope and covered with earth. On December 21st, 1887, the Municipal Gas Company, whose property was on the line of said sewer about 3 500 ft. distant, was being supplied with naphtha by the Vacuum Oil Company through an underground pipe connecting the two properties. The naphtha was forced by pumps to a tank at the gas works. A short time prior to the delivery of the last large supply of naphtha, the connecting pipe was broken at an undiscovered point in the vicinity of a rock excavation adjacent to the line of the aforesaid main sewer, and about 15 000 galls. of the naphtha was pumped into the sewer instead of being delivered into the tank. The naphtha was carried along on the sewage until the whole length of the sewer to the outlet at the river was charged with its vapor. By some means fire was communicated to it through an untrapped lateral sewer, and an explosion occurred that blew up the Jefferson Mill, as well as many of the manholes along the line of the sewer, the flames at every point of issue rushing out to a height of 30 to 40 ft. The resulting fire destroyed the Jefferson Mill, as well as the adjoining Hinds' Mill, leaving them in ruins, as well as causing the loss of five human lives. The Clinton Mill had been burned down some time previous. The Hinds' Mill was rebuilt in 1888, but the others were as left by the fires when the Citizens' Light and Power Company purchased the property. This was the condition of things when the writer was called on to plan an electric-light station.

The Jefferson Mill had two water wheels located near *A*, Fig. 1, operating under a collective head of 56 ft. The discharge from these wheels, as well as that from the Hinds' Mill, ran to the pond *B*, which had a dam at the west side of Falls Street. The water from this pond was used on the two wheels *C* and *D*, with a head of about 25 ft., power from these lower wheels being transmitted to the Hinds' and Jefferson mills by means of wire rope.

After due consideration of all the essential features, the plan as shown on Fig. 2 was decided upon, the whole station being placed below the site of the mills upon what was considered almost useless land. As the race front was the portion that gave value to the property, the Company possesses the same race frontage intact, while

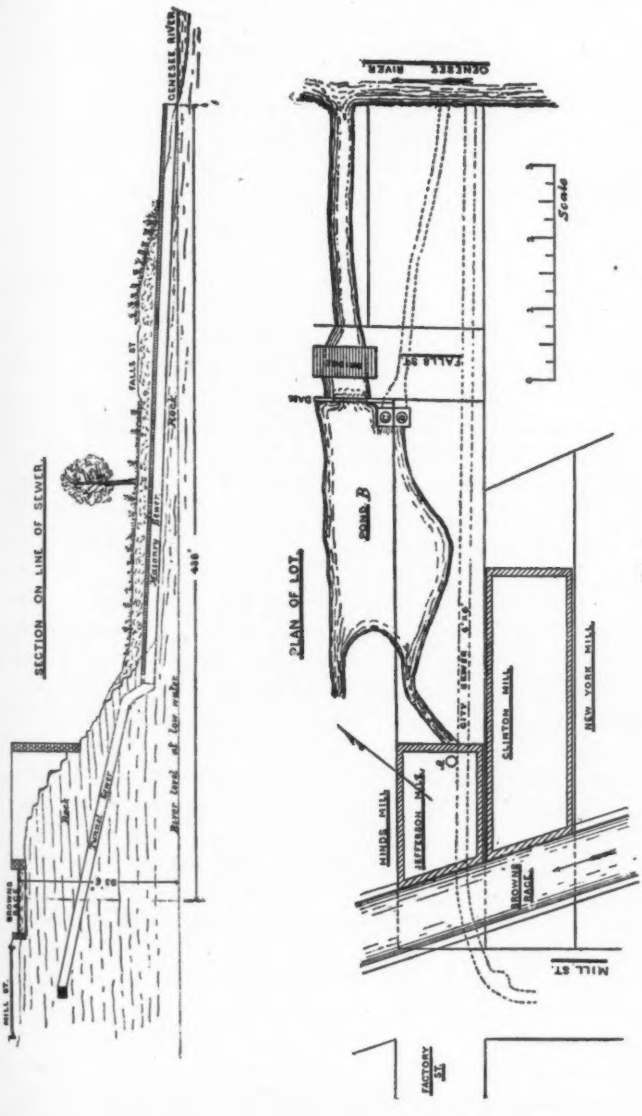

SECTION ON LINE OF SEWER.
GENESEE RIVER
FALLS ST
Masonry Sewer
Rock
Tunnel Sewer
River level at low water
438'
BROWNS RACE
MILL ST.
PLAN OF LOT.
POND B
DAM
FALLS ST
CITY SEWER
CLINTON MILL
NEW YORK MILL
HINDS MILL
JEFFERSON MILL
BROWNS RACE
MILL ST.
FACTORY ST.
Scale

FIG. 1.

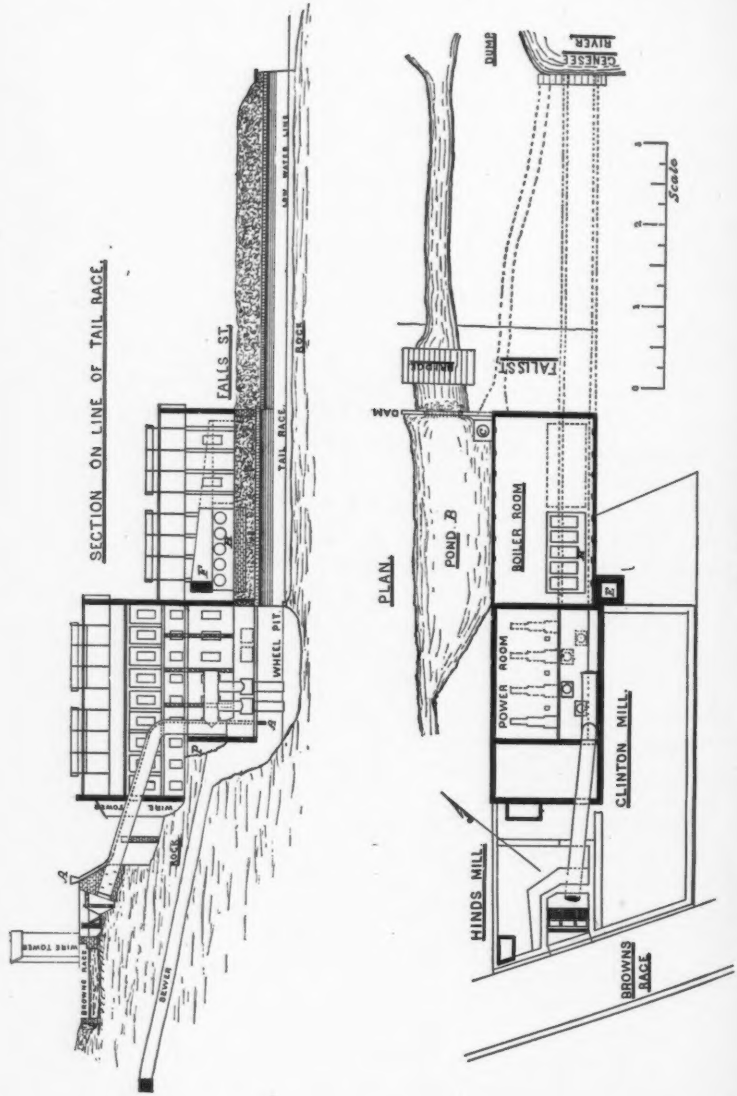

SECTION ON LINE OF TAIL RACE.
FALLS ST.
TAIL RACE.
LOW WATER LINE
ROCK
WHEEL PIT.
WIRE TOWER
BROWNS RACE
ROCK
SEWER
PLAN.
POND B
DAM.
BRIDGE
FALLS ST.
DUMP
GENESEE RIVER
BOILER ROOM
POWER ROOM
CLINTON MILL.
HINDS MILL.
BROWNS RACE
Scale
0
1
2
3

Fig. 2.

it has acquired a complete power station besides. Work was commenced on the 28th of November, 1892. As the discharge from the sewer was continuous, and had to be maintained while the work was being prosecuted, the first step taken was to direct the sewage water into the pond *B*. This was successfully done by a large wooden trough placed at such a point in the sewer as would pass the water by gravity into the pond *B*. A coffer-dam of sufficient dimensions and height was placed at the river end, so as to shut out the river water in its various fluctuations. Steam pumps kept the water down, so that the rock at the lower end was bared, and upon this the masonry of the side walls of the tail race was commenced, and carried up to 6 ft. above low water-mark of the river. The race was made 13 ft. wide in the clear. An arch of 7½ ft., internal radius was thrown across the top. The rock was excavated in the center of the race 2 ft. below the low water-mark, which was considered the datum point of the whole work. This construction was carried out in open cut (the old sewer being removed as the work progressed) to a point coinciding with the west side of Falls Street, a distance of 165 ft. from the river face of the tail race. Here a change was made, making the arch semi-circular, with an internal radius of 6½ ft. This was done in order to better support the superincumbent weight of steam boilers that were placed directly over the tail race, as shown on Fig. 2. These dimensions were maintained for a distance of 95 ft. west of Falls Street, making a tail race proper 260 ft. long. At this point the wheel pit commences. The side walls of the race are built 2 ft. thick, and a skew-back placed 6 ft. above the datum line to receive the arch, which was also 2 ft. thick. The face of tail race masonry at the river end is rock-faced, and is carried up above the top of the arch and covered with point-dressed coping stone. At the inner end of the tail race, adjoining the wheel pit, is placed a level sill or spill, whose top is 1 ft. above the datum, to maintain a seal of the draft tubes of the water wheels. The wheel pit was enlarged by under-cutting the rock, as shown by Fig. 3, and deepened, so that its bottom is 6 ft. below the bottom of the draft tubes. This gives free discharge to the water from the wheels and prevents any reaction. The pit is 64 ft. long, and on the wheel floor is 14 ft. wide in the clear. The wheels are supported on double 16-in. steel I beams, resting 2 ft. in the rock at the ends, in recesses cut therein. Above the wheel floor the pit is lined with 12. ins of brick work on the sides. The ends of the I beams

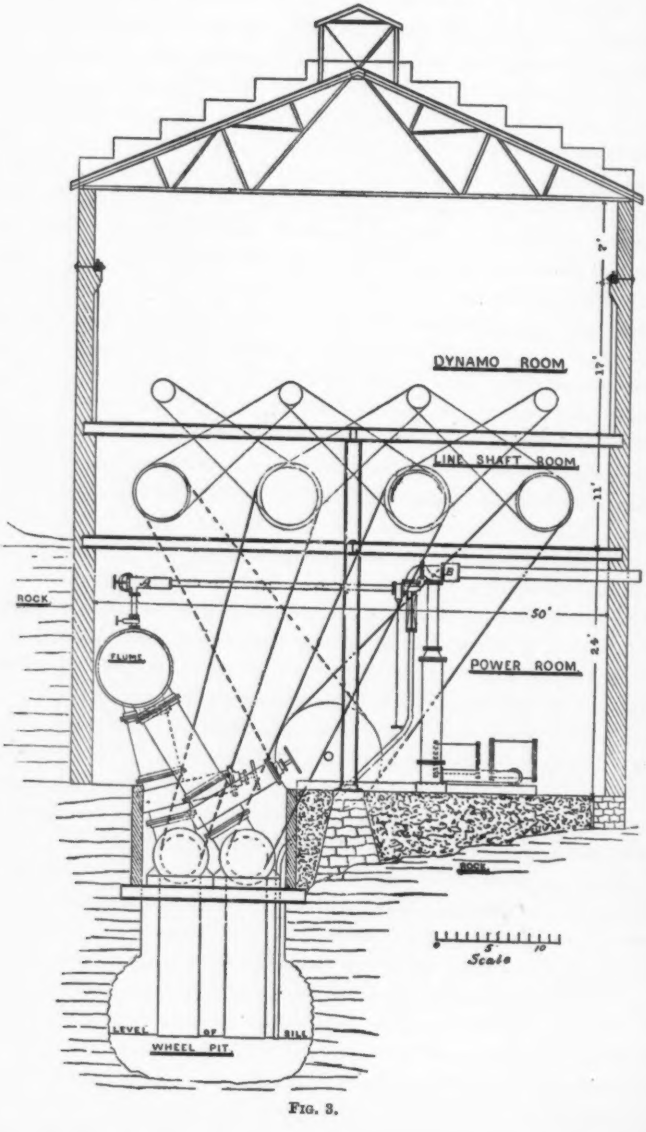

DYNAMO ROOM
LINE SHAFT ROOM
POWER ROOM
ROCK
FLUME
ROCK
7'
17'
11'
24'
50'
LEVEL OF SILL
WHEEL PIT
0 5 10
Scale

FIG. 3.

are solidly built up with brick, filling the recesses. The wheel floor is laid with 2-in. matched and surfaced hemlock plank. Upon this at right angles to the plank is laid 1¼-in. planed and matched hard maple flooring, with a layer of asbestos flooring paper between the two. This was done in order to cut off any possible odor arising from the sewer. The wheel pit floor is 15 ft. 3 ins., and the power-room and boiler-room floor 25 ft. above the datum line.

By the 8th of March, 1893, the tail race, wheel pit and the foundation of boiler house were completed, and the sewage was turned into the wheel pit. All of this masonry was laid in American Portland cement, of the Columbia brand. The work was prosecuted continuously, excepting Sundays, during the whole of the cold winter of 1892-93, the temperature being as low as -6° Fahr. at times. But one half day was lost during the whole time, when a sleety rain that froze as it fell rendered it impossible for the men to retain a foothold on the work. All the mortar was salted, to prevent freezing. The foundation of the buildings and chimney are all upon the rock, with the exception of a short space where the water wheel D, Fig. 1, had been removed.

On March 16th the brick work of buildings and chimney was commenced. The walls of the boiler house, as well as the chimney, are laid in quick-lime mortar, but all the rest of the whole work is laid in cement mortar. For the main building the walls were laid as follows:

An inside and outside course of wall was laid two bricks high, then the center of the wall was filled with grout and the bricks placed in the grout, the bricks having been previously wetted. Headers were introduced every seven courses, and alternated on the inside and outside of the walls. All bricks were hard-burned sewer bricks, and joints were struck on the inside and outside of the walls. When completed, the inside faces of all the rooms were painted with white Aquol paint. The walls of the boiler house are 12 ins. thick, and reinforced on the inside by 4-in. pilasters, 16 ins. wide, placed immediately under the roof trusses, spaced 10 ft. 4. ins. apart, centers. The walls are 24 ft. high to the eaves, with a gable on Falls Street.

The walls of the main building are 59 ft. high from foundation to eaves, divided into a power-room 24 ft. high, and a line shaft-room 11 ft. high. To this height the walls are 2 ft. thick. At the floor of the dynamo-room the wall is reduced to 20 ins. thick, and reinforced on

the inside with 4-in. pilasters 20 ins. wide, spaced 10 ft. 4 ins. apart, centers. At a point 17 ft. above the floor the brick are corbelled out, joining the pilaster heads and forming a bearing for a line of 8 x 8-in. white oak stringers, which are bolted through the walls, to carry an overhead traveling crane. Above this the walls are carried up to the eaves, 20 ins. thick.

The buildings are covered with steel-trussed roofs, having a rise of 13 ft. in the center. Principals are spaced 10 ft. 4 ins. apart, centers. Span of dynamo-room, 50 ft.; and of boiler-room, 48 ft. Each roof has two ventilators, for light and air, which are about 30 ft. long each. Upon the trusses steel purlins of 6-in. channel beams are fastened on edge. To the web of these purlins are bolted 2 x 6-in. stringers. To these are nailed the roof boards of $1\frac{1}{8}$-in. flooring, and the whole covered with sanded tar roofing paper.

As the sides of the Jefferson lot are not parallel, being 50 ft. wide at Falls Street and only 48 ft. 9 ins. wide at a point coinciding with the west end of the main building, an agreement was made with the Hinds' Mill Company to place so much of the building upon their property as would make the buildings parallel. As a consideration therefor a party-wall interest in the north wall of main building was given them. By this arrangement the roof trusses were uniform, and the result was a considerable saving in the cost of roof construction.

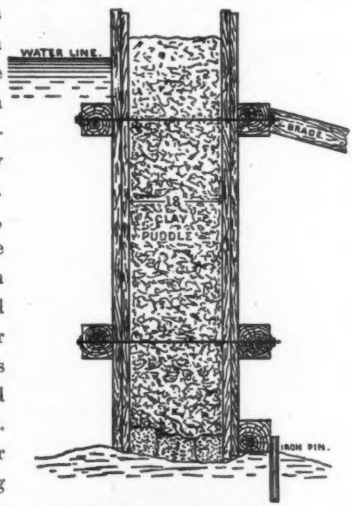
A chimney is located as shown at E, Fig. 2, into which are carried, by the smoke jack F, the smoke and gases from the batteries of boilers. The chimney foundations are on the rock. It is 14 ft. square at the base, and is carried up 125 ft. high, with a straight flue 8 x 8 ft.

As soon as the season was advanced far enough to preclude freezing, the space in the boiler-room over the tail race was filled and solidly rammed down to a depth of 6 ft. below level of floor, and a solid foundation of rubble work, laid in cement mortar, was built to receive the boiler setting for the first battery of five boilers, as shown by Fig. 2.

On Sunday, May 7th, an accident occurred that resulted in the carrying away of the west wall of the power-room. A heavy freshet was running in the river, and the man having charge of the inlet gates to Brown's Race, by some miscalculation, allowed so much water to enter that it overflowed the old race wall at the company's property, and ran down and filled the pocket P, Fig 2, and, being confined between the rock and the wall, the hydrostatic pressure was great enough to

throw the wall in large masses into the power-room and wheel pit. The wall was 50 ft. long by 23 ft. high by 2 ft. thick. It started at the bottom, as shown by the position in which it lay, actually tearing out the rock which was still clinging to the brick work at the bottom.

The old race wall was very defective and was replaced with a new wall, the whole length of the front of the property being 103 ft. 6 ins. As the water in the race could not be let out excepting on Sundays between the hours of 8 A. M. and 5 P. M., it was necessary to put in a coffer-dam while the wall was built and the head gates put in place. All the material was made ready for a speedy placing in position of the dam, and on Sunday, May 28th, it was successfully accomplished in the allotted time. The bottom of the race was rock, rather irregular on top, and the use of flour sacks partly filled with dry cement mortar was resorted to, in order to fill the gaps under the sheet piling, a layer of bags being placed at the bottom and tamped down so as to pack closely. The cement absorbed the water and set as a solid stone, filling every crevice, the interior being filled with 18 ins. of clay puddle,



SECTION OF COFFER DAM.
FIG. 4.

also rammed down. In order to prevent the dam from slipping on the rock, holes were drilled in the rock about 6 ft. apart along the line of the race wall, and 1½-in. round iron pins dropped into them. A hemlock stringer 6 × 6 ins. was laid against them on the rock and the first course of sheet piling nailed to it. The girts above were 6 × 6 ins., and were stayed with ⅝-in. bolts and cast-iron washers, to prevent the puddle from spreading the dam. The first course of sheet piling on each side was 1½ ins. thick, and another course of 1 in. was fastened over, to batten the joint. Fig. 4 shows a section of the coffer-dam. The old race wall was removed in sections and replaced by the new wall; the rock was removed and part of the forebay with the

head gates in position was built, and water was turned in against the gates by July 18th, although the coffer-dam was not removed until August 14th. Fig. 5 shows arrangements of head gates, forebay, racks and flume. The arrow indicates the direction of the water as it flows in the race. *A A* is the race wall with an opening in front of the forebay 21 ft. wide, which is spanned by three 16-in. steel I beams, supported in the center by an iron column *C*. The opening is widened out on the inner face of the race wall to 26 ft., so as to give easier

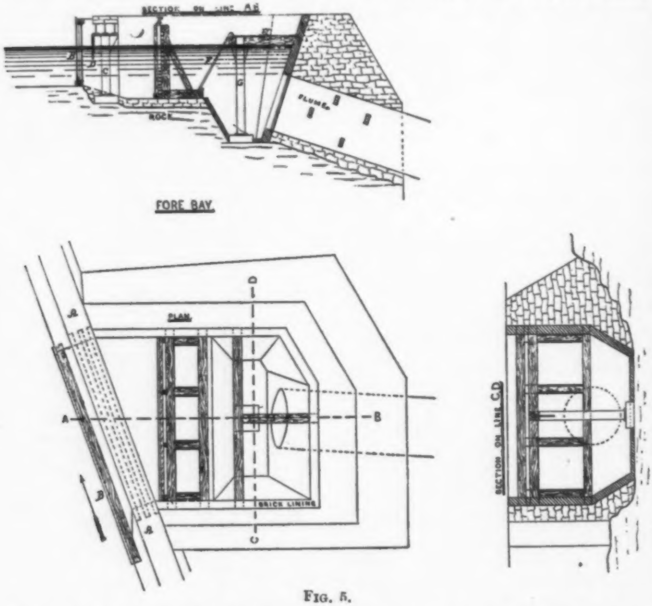


FIG. 5.

entry of water unto the forebay. This opening is guarded by coarse rack *B*, made of $1\frac{1}{4}$-in. round iron bars spaced 6 ins. apart, and serving to stop any large pieces entering the forebay. On the face of the column *C* is a bracket supporting a wide plank *D*, 2 ins. thick, which has its lower edge 1 foot below the surface of the water. This keeps out much of the floating débris carried along with the water, such as shavings, straw, leaves, etc. The gates *E* are placed inside the wall, so that they are protected by the building to be erected. Temporarily they are now enclosed in a frame shanty. The fine rack *F* is set at an

angle of 60°, so that in clearing off the rack the débris is drawn and deposited on the platform *H*. Cast-iron column *G* carries a 12 × 12-in. oak timber that holds the head of the fine rack *F*. A No. 10 wrought-iron slush pipe *A*, Fig. 2, is carried along the top of the flume outside, terminating below the floor of the wheel pit, and is designed to carry the débris raked from the fine rack directly into the wheel pit. Fig. 6 shows head-gate construction in detail. All the gate frame is made of

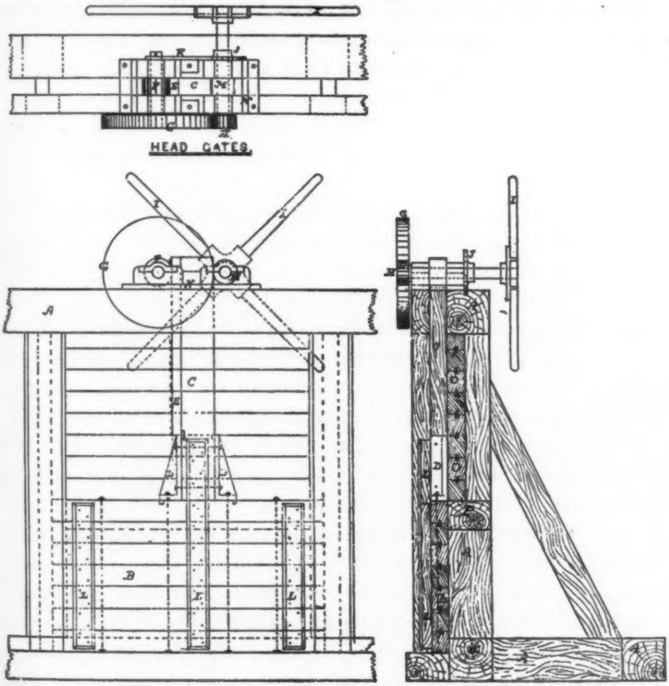


FIG. 6.

12 × 12-in. white oak, fitted with double mortise and tenons, and all bolted and put together at joints with red lead and oil. The gates *B* are made of seasoned white oak plank, 5 ins. thick and 6 ins. wide, with a $\frac{3}{4} \times 1\frac{1}{4}$-in. tongue strip between the planks. These are all jointed with red lead and drawn together with 1-in. bolts and battens *L* secured by $\frac{5}{8}$-in. lag screws. There are three gates, each covering a water-way 5 ft. 4 ins. × 2 ft. 6 ins., all the water being admitted below girt *P*. The

space between the top frame and girt *P* is filled with the same material and form as the gates themselves. The rack staff *C* is 5×9 ins. oak and fastened to gate *B* by the cast-iron brackets *D*, all thoroughly bolted. On the side of rack staff *C* is fastened a straight rack *E*, with the teeth boxed. The bed plate *N* contains the raising mechanism. The pinion *F* has 12 teeth, boxed, and is 2 ins. pitch and 4 ins. face, meshing into the teeth of rack *E*. On the outer end of the shaft carrying pinion *F* is a spur wheel *G*, having 55 teeth, $1\frac{3}{4}$ ins. pitch, and $3\frac{1}{2}$ ins. face. Into this gears the pinion *H*, having 12 teeth. The shaft operating the pinion *H* has on its other end a spider hub fitted with lever arms *I*. A loose collar *M* plays on the shaft and acts as a roller against the back of the rack staff *C*. A rachet wheel *J* is keyed on this shaft and engages the pawl *K*, which retains the gates at any height.

Fig. 7 shows details of fine rack construction. Sections 2 ft. wide are made, so as to allow of easy removal, instead of making the rack all in one piece, as is usually done. The tie rods are $\frac{1}{2}$ in. diameter, with countersunk head let into the first bar of a section. The thimbles are made of $\frac{1}{2}$-in. wrought-iron pipe. Alternately the thimbles and bars are slipped on the bolts, and, when screwed tight together, the $\frac{1}{2}$-in. nut on the end maintains a like spacing. The bars are $\frac{1}{4} \times 2$ ins. in section, and are turned edgewise to a 2-in. inner radius at the upper end, the better to land the rakings on the platform. The holes for rods are drilled $\frac{5}{8}$-in. centers from the back of the bar, so as to allow the rake teeth to clean the rack.

Fig. 8 shows the general arrangement of the engines and water wheels in the power-room. The room is 50 ft. wide by 64 ft. long; the wheel pit, as before stated, is 14 ft. wide by 64 ft. long, leaving the engine floor 36 ft. wide, giving space enough to place four horizontal engines of 500 H. P. each.

The water wheels are twin Poole-Leffel central-discharge turbines, 23 ins. in diameter, and at a speed of 560 revolutions per minute, under a head of 92 ft. 6 ins., develop 500 H. P. each, with a discharge of 3 800 cu. ft. of water per minute. The wheels proper are made of phosphor bronze with buckets of Otis steel, tinned. The wheel bedplates are heavy cast-iron box sections, machined and bolted together with heavy bolts fitting reamed holes. The wheel shaft is $4\frac{7}{8}$ ins. diameter, running in adjustable babbet-lined bearings. A rope wheel

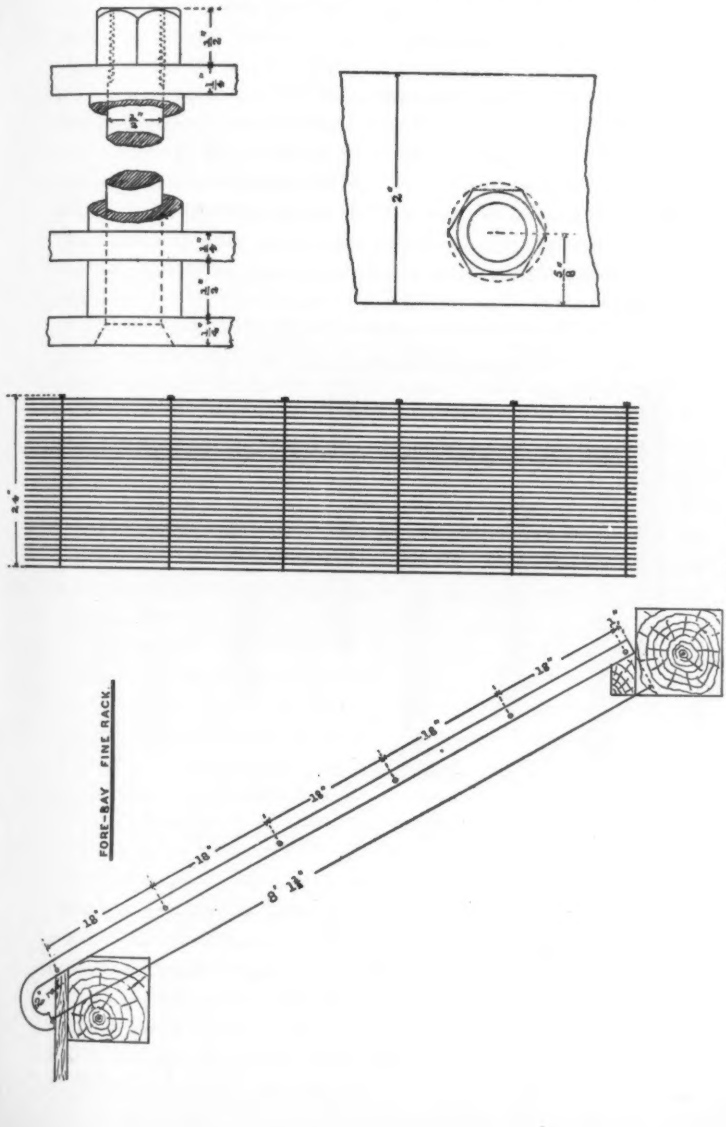


FIG. 7.

4 ft. in diameter is keyed on the shaft, and is grooved for fifteen 1¼-in. Manilla "stevedore" ropes, made with four strands and a core, worked in with plumbago in the process of making. From the 4-ft. wheel, 15 ropes run to a rope wheel on the line shaft above, 76.8 ins. in diameter, and grooved for sixteen 1¼-in. ropes. The rope being endless, the idler strand is passed over a 5-ft. single grooved wheel, placed in a movable frame. The frame traverses in iron guides and maintains by its weight a constant tension on all the ropes. This is made adjustable for the amount of tension, by the application of counter-weights to the frame. The speed of the line shafts is 350 revolutions per minute, and the rope travel is 7 037 ft. per minute.

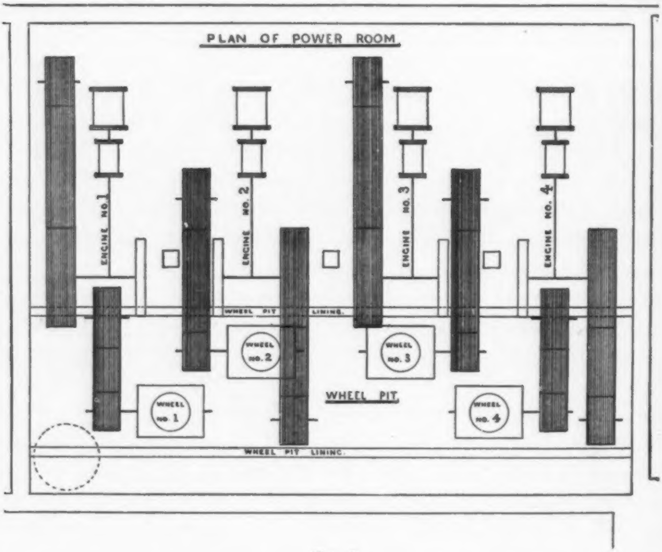


FIG. 8.

The water wheels are supplied from a steel flume 7 ft. in diameter, as shown on Fig. 2. From the horizontal portion of the flume a 4-ft. pipe leads down to each wheel and has a geared 48-in. Chapman valve at the lower end, between pipe and penstock, as shown on Fig. 3. These valves are fitted with a 12-in. by-pass, for the purpose of equalizing the pressure on both sides of the large valve, in opening or closing.

Fig. 9 shows the steel flume. From the forebay to the flange A, at the bottom of the elbow, the plates are $\frac{5}{16}$ in. thick. All below flange *A* are $\frac{3}{8}$ in. thick. The $\frac{5}{16}$-in. portion is all single riveted. The longitudinal seams of the $\frac{3}{8}$-in. portion are double riveted. Bottom head *B* is $\frac{1}{2}$ in. thick and flanged to an internal radius of $1\frac{1}{2}$ ins. Head *C* is $\frac{1}{2}$ in. thick and convexed to a radius of 7 ft. The center of this head is stayed to the second sheet from the end by eight $1\frac{1}{4}$-in. bolts. Bolts are spaced through head on an 18-in. circle. Flanges *A D D* are made of 3 x 3 x $\frac{7}{16}$-in. angles, and are held together by 132 bolts $\frac{3}{4}$ x $2\frac{1}{2}$ ins. Joint packing was made of $\frac{1}{2}$-in. solid round rubber. At the upper end of the flume, where it is built in the forebay, an angle-iron ring of 4 x 4 x $\frac{1}{2}$ ins. is riveted outside and 18 ins. from the end.

This is to form a stop water, as well as an anchor. Besides this, short pieces of 3 x 3 x $\frac{7}{16}$-in. angle are riveted on the outside, to securely anchor the pipe in the masonry. All the variation due to contraction and expansion is absorbed at the elbow. At the junction of the horizontal and vertical portions of the flume two $1\frac{1}{2}$-in. stay bolts E, with nuts and packing on the inside and outside, run through the pipe. These are designed to prevent any dilation or distortion at that point. The flume at bottom head *B* rests upon steel I beams, and upon the rock. The flume complete weighed some 31 tons. All was coated with two coats asphalt paint, inside and out.

A horizontal "Woodbury" compound, condensing, slide-valve engine with extra heavy bed plate, is set in the power-room at point marked in Fig. 8 "Engine No. 1." Steam cylinders are placed with the large cylinder outside, so that pistons and rod may be easily removed. Cylinders are 19 ins., and 31 x 24-in. stroke. At 167 revolutions, with a boiler pressure of 110 lbs. per square inch, vacuum 22 to 24 ins. and cutting off at $\frac{5}{16}$ stroke, the engine is rated at 500 H. P., and is guaranteed to produce a horse-power on an evaporation of 20 lbs. of water per hour. The crank shaft is a steel forging in one piece. Journals are $11\frac{1}{2}$ ins. diameter by 21 ins. long. Crank pin, $11\frac{1}{2}$ ins. diameter by $8\frac{1}{4}$ ins. long. The end carrying the rope driving wheel has an outboard bearing. Governor balance wheel is $8\frac{1}{2}$ ft. diameter by 25 ins. face. Rope driving wheel in halves and 10 ft. 6 ins. diameter and grooved for fifteen $1\frac{3}{8}$-in. ropes. These ropes lead to a 5-ft. rope wheel on the line shaft above, with same arrangement for tightener as is applied to the water wheels.

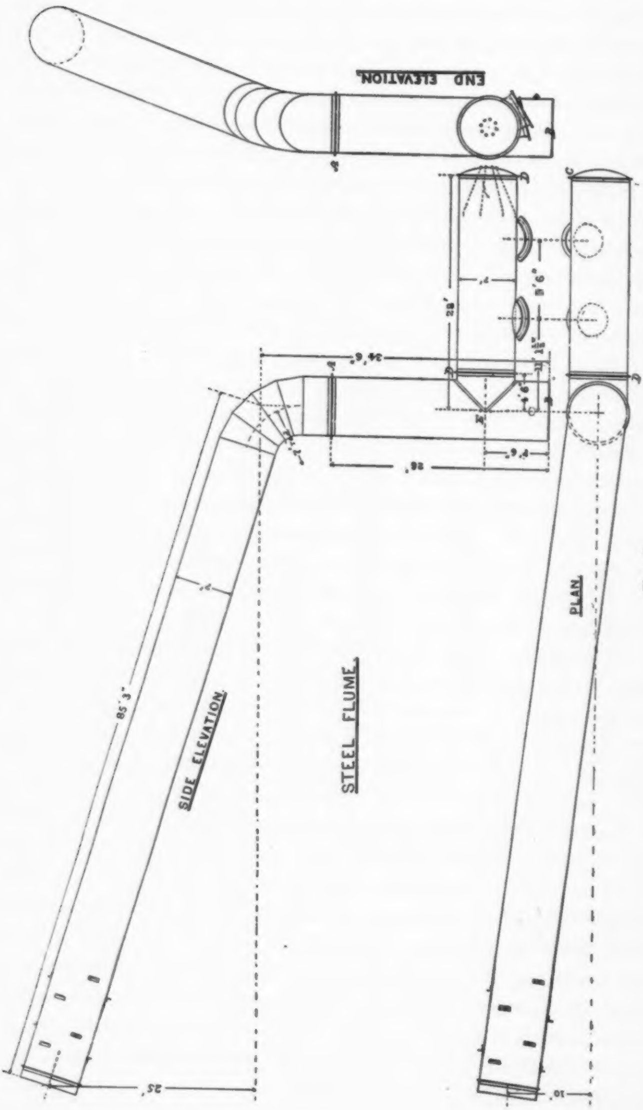
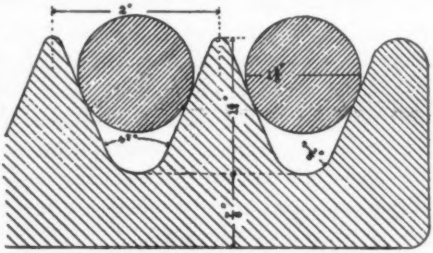

STEEL FLUME
SIDE ELEVATION
PLAN
END ELEVATION
85' 3"
28'
34' 6"
26'
25'
10'
5' 6"

Fig. 9.

Fig. 10 is a section of rope driving wheel rim, and gives angle of grooves, pitch and sizes as shown. Rope speed of engine drive is 5500 ft. per minute.

The condenser applied is H. W. Bulkley's jet condenser and heater combined. It is shown in position on Fig. 3. The injection water is taken from the horizontal portion of the flume, and is supplied under a pressure of 22 lbs. per square inch. The vacuum maintained is 27 to 28 ins. In its performance it is very satisfactory. A strainer box *A*, Fig. 3, is placed in the supply pipe and contains a copper wire strainer of $\frac{3}{16}$-in. mesh, that is arranged to be quickly removed and replaced by a clean one. The strainer is for the purpose of catching any floating matter that might clog the injection jet, and prevent the condensation. An automatic valve *B* is placed above the condenser, so that the engine can operate non-condensing.



SECTION OF ROPE WHEEL RIM.

FIG. 10.

The boiler-room and boilers *H* are shown on Fig. 2. The house is designed for ten 200-H. P. boilers, only five of which are now in place, space being left for the other five when needed. They are set in one battery. Boilers are horizontal-tubular, set in brick work. Each boiler is 66 ins. in diameter and contains seventy-two $3\frac{1}{2}$-in. tubes, 18 ft. long. The shell is made of three plates, each long enough to reach entirely around without piecing. All the longitudinal seams are placed so as to be above the reach of the fire. Shell plates are $\frac{13}{32}$ in. thick, and all edges planed for calking. All rivet holes are drilled, and any variation of holes was corrected by reaming, no drift pins being used for that purpose. Heads are $\frac{1}{2}$ in. thick and flanged with an internal radius of $1\frac{1}{2}$ ins. Tube holes in heads were drilled and chamfered on both sides. Tubes are American lap-welded, of charcoal iron, set with expander and beaded over on the outside. The horizontal seams are butt seams, with a plate on the outside $9\frac{3}{4}$ ins. wide and one on the inside 15 ins. wide, with triple rows of rivets each side of the joint;

all proportioned to the standard of the Hartford Steam Boiler Inspection and Insurance Company. Each head is stayed to shell with solid crowfoot stays of 1-in. square iron, equal in quality to Burden's best iron. Each boiler has a steam drum 33 ins. in diameter by 38 ins. high, and is supported in brick work by four lugs near the front end and four near the rear end. The rear lugs rest on iron rollers 1 in. in diameter on suitable plates set in the brick work. Front lugs are built solid in the brick. Calking is the Connery system. The boilers are intended for a pressure of 110 lbs., and were proved with a hot-water pressure of 180 lbs. per square inch. The feed water enters the boilers through the front head above the tubes, and is distributed in the boiler through a perforated $2\frac{1}{2}$-in. pipe. Each boiler is equipped with water column and gauges, pop safety valve, asbestos-lined blow-off cock, and all the necessary water-stop and check valves, so that the boilers may be used independently, or as one battery. Each boiler has two manholes, one on top and one in the front head below the tubes. All the material in the plates and heads is Park Bros. open-hearth, homogeneous flange steel, with a tensile strength guaranteed between the limits of 55 000 to 62 000 lbs. per square inch of section, and limit of elasticity between 35 000 and 40 000 lbs. per square inch. The boilers are supplied with water by a duplex Worthington pump, with 9-in. steam cylinder, $5\frac{1}{4}$-in. water cylinder by 10-in. stroke, taking the water from the flume through a strainer-box. The boiler house is paved with hard brick, laid herring-bone on edge, grouted with cement mortar, and bedded on 8 ins. of concrete. The smoke jack is of No. 10 iron, built on a skeleton frame of $2\frac{1}{2} \times 3 \times \frac{5}{16}$-in. angles. A damper is arranged from each boiler in smoke jack. As shown, it is graduated in size, being 5 x 10 ft. at the chimney end. It was painted with two coats of asphalt paint inside and out.

Fig. 11 shows plan of line-shaft floor. Shafts are of hammered iron 5 ins. in diameter, and arranged with heavy floor pedestals, fitted with self-adjusting, ring-oiled, babbet-lined bearings. The rope wheels are placed on heavy cast-iron quills, furnished with Hill friction clutches of 500 H. P. capacity each. By a series of jaw clutches, pulleys and belts any line shaft can be operated from any water wheel or engine, all the line shafts making the same number of revolutions.

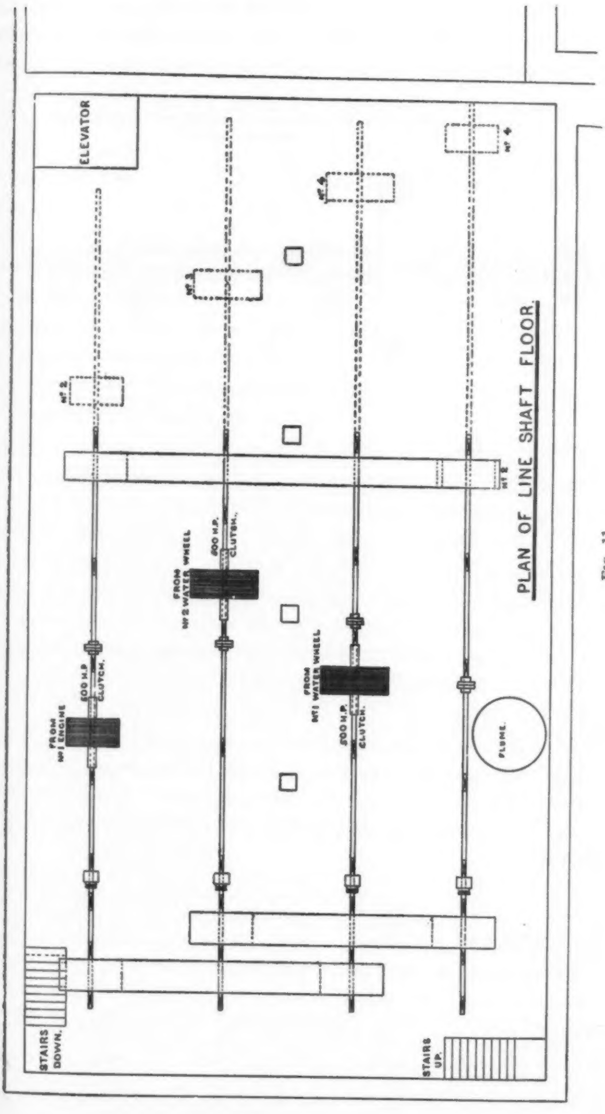

PLAN OF LINE SHAFT FLOOR.
ELEVATOR
STAIRS DOWN.
STAIRS UP.
FROM No 1 ENGINE
500 H.P. CLUTCH.
FROM No 2 WATER WHEEL
500 H.P. CLUTCH.
FROM No 1 WATER WHEEL
500 H.P. CLUTCH.
FLUME.
No 2
No 3
No 4

Fig. 11.

Fig. 12 shows in detail the quill, clutch and bearings. The floors of the line-shaft and dynamo rooms are made of steel I beams, built and anchored into the walls at outside ends, and attached in the center to

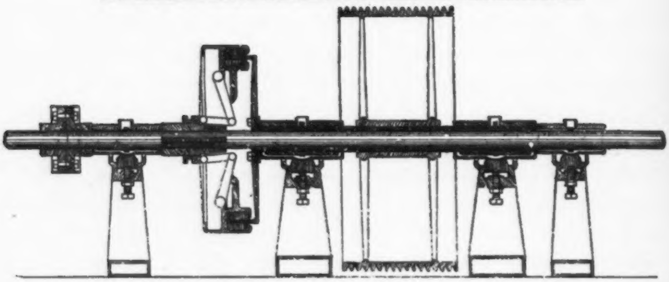


FIG. 12.

longitudinal girders of heavy steel I beams. Girders are supported on columns formed of channel beams and lattice bracing. Columns rest on cap-stoned masonry carried down to the rock.

The wooden floors are made of 2 x 6-in. hemlock plank, matched and surfaced and spiked to fitting strips under flange of I beams. Upon this, and laid at right angles to the hemlock, is nailed $1\frac{1}{8}$ x 4-in. matched, seasoned hard maple.

All of the stone used in the work was quarried stone, as the rock cut out was a shale that disintegrated on exposure, and was fit for nothing but filling.

The brick were hard-burned sewer brick, wetted as they were laid.

The cement used was the Columbia brand of American Portland. The result of five tests of this cement, made by O. H. Peacock, Esq., Engineer of the East Side Sewer Commission, of Rochester, N. Y., is appended.

	Briquette made.	Put in water.	Broken.	Tensile strength per square inch.	Time of immersion.
				Pounds.	
1...	Aug. 24, 1892, 3 P. M.	3.30 P. M.	Aug. 25, 1892, 3.30 P. M.	225	24 hours.
2...	Aug. 24, 1892, 3 P. M.	3.30 P. M.	Aug. 25, 1892, 3.30 P. M.	255	"
3...	Sept. 12, 1892, 10.25 A. M.	10.55 A. M.	Sept. 13, 1892, 11.30 A. M.	210	"
4...	July 19, 1893, 10.10 A. M.	11 A. M.	July 26, 1893, 11 A. M.	446	7 days.
5...	Aug. 21 1893, 3 P. M.	3.30 P. M	Aug. 28, 1893, 3 P. M.	535	"

All of the rock cutting, excavating and stone and brick work was performed by the firm of Chambers & Casey, of Rochester, N. Y., they also furnishing all the materials and tools to complete the buildings.

The water wheels were built and erected by the firm of Robt. Poole & Son Company, of Baltimore, Md.

The engine and boilers were from the Stearns Mfg. Co., of Erie, Pa.

The steel floors, roofs and flume were furnished by the Rochester Bridge Works, of John F. Alden.

Line-shafting bearings, friction clutches and pulleys were supplied by the Hill Clutch Company, of Cleveland, O.

The carpenter work was performed by R. Williamson; the windows, doors and frames were from the Ocorr & Rugg Company; the smoke jack and slush pipe and roof covering were furnished by the John Siddons Company; the steam piping, pumps and plumbing by Barr & Creelman, all of Rochester, N. Y.

DISCUSSION.

William P. Craighill, Prest. Am. Soc. C. E.—I did not expect to say a word concerning the interesting paper presented by our friend Mr. Cartwright, but, before the discussion begins, I will take the liberty of emphasizing several points he has made.

One is the great care which should be taken in the construction of brick masonry in order to insure good results. Two cases may be mentioned which were a part of my experience more than 40 years ago. They are of a special and unusual character. I refer to Fort Pulaski, on the Savannah River, and to Fort Sumter, in Charleston Harbor.

These forts were then unfinished. Later, in the Civil War, much of their masonry was greatly broken to pieces by the guns of General Gillmore. After the war, when repairs and reconstruction began, the importance was very clearly shown of the truth of one of Mr. Cartwright's cautions, viz., the necessity, in order to have the best brick masonry, of great care in seeing every brick carefully soaked in water before being laid. It is not enough to have the bricks simply damp. They should be soaked so as to be dripping when laid. And, to this end, every mason should have his barrel or tub of water near him in which his bricks may be soaked before being used, and an inspector should be around to see it properly attended to. The result proved again the importance of this precaution, for in the masses of masonry

at Forts Pulaski and Sumter, broken up under those peculiar circumstances, it was found that the adhesion of the mortar to the brick was greater than the cohesion of the particles of the brick among themselves.

I recollect well how this watering of the bricks was insisted on by my then chief, General Totten, in his detailed instructions to his young subordinates. The farther south I went, as, for instance, at the Dry Tortugas, in the Gulf of Mexico, the more stress was laid upon it.

There is another point to which Mr. Cartwright referred, the use of salt in masonry in freezing weather. This may be of great value in special cases. Take, for instance, one like the Great Kanawha River, where, in building locks and dams, much of the work must be done in coffer-dams. The Kanawha is a very uncertain, inconstant stream. The freshets come often and unexpectedly, and sometimes very high. To keep them out would require coffers of very great height with proportionate expense and inconvenience of use at lower stages. Advantage should therefore be taken of every hour when the coffers are not flooded, to expedite the work. The masonry on the Kanawha is of stone and concrete.

There is one more point to which I will refer, the danger of too much dependence on mathematical formulas. Our education as engineers leads us, and very properly too, to value our mathematics and formulas most highly, and the man who undervalues them, or tries to dispense with them, is a very unwise one. But we should avoid both extremes, and this is a safe rule in almost all departments of life.

In hydraulic work of the special kind to which most of my attention has been given for many years past, the improvement of rivers and harbors, there are so many conditions to be taken into account, which are very variable, even from hour to hour, and so many of which we know little, and about which we must accept mere theories, that the formulas must be used with great care in order to avoid serious mistakes. Even when we are applying formulas to cases like masonry, bridges, etc., where the materials are few and well known and we have varied experiences, we find it necessary to have large factors of safety.

I will not detain the Society longer from the discussion of Mr. Cartwright's interesting paper, and we will now be glad to hear any one who may wish to speak on the subject.

H. W. Brinckerhoff, M. Am. Soc. C. E.—I would like to ask Mr. Cartwright how he got along with his masons with the use of very wet bricks? The masons, I know, complain that very wet bricks soften their fingers.

Bernard R. Green, M. Am. Soc. C. E.—Having, unfortunately, but just come in, I did not hear the paper read, and perhaps am out of order; but I do not understand why the bricklayers' hands should have been so much injured in laying wetted bricks in cement mortar.

I have laid many millions of bricks in that way and never observed serious results of that kind. The bricklayer does not necessarily put his hands into the mortar. He handles the clean, wet brick with one hand and the mortar with the trowel in the other. The bricks should be well dampened, but not soaked. The experience referred to, however, by the author may have been in some other sort of work than I have supposed.

Charles E. Emery, M. Am. Soc. C. E.—I had intended to say but a few words. The paper, to a certain extent, explains itself so entirely that there is little opportunity for discussion. I have seen one of Mr. Cartwright's plants in operation at Rochester in which rope transmission is used, and it operated very perfectly, and was a very satisfactory piece of work. The very thorough way in which Mr. Cartwright does his work is to be commended, and I am sure we must feel very grateful to him for the careful manner in which he has presented an example here.

Referring to the criticism of formulas brought out in the discussion, I will say that the fault of some formulas is that they are not correctly founded on facts, or are incorrect in form. A correct formula, with correct constants, based on careful experiments, will always give correct results. The difficulty is that the mathematicians and physicists do not always take proper pains to obtain correct constants, while practical men who attempt to formulate experimental results frequently attempt to construct the formula too simply, so that it is little more than the rule of three, and thereby make it inapplicable, except for conditions closely approximating the experimental ones. I have never had any difficulty in solving questions in regard to expansion by simple calculations. Such calculations frequently require the combination of rules relating to linear expansion with those for the transverse strength of girders, but the method is evident; there should be no difficulty in ascertaining just how much pipes can be permitted to bend before becoming over-strained. It was only a few days ago that an engine-builder asked my advice about connecting the horizontal cylinders of a cross compound engine rigidly, by means of piping under the floor. They had been accustomed to make such connections in the smaller engines, but in this case the superintending engineer objected. Simple calculations showed that if it were possible to hold the two engine foundations rigidly in position, the compression would not be beyond the limit of elasticity of the metal of the pipes, even if the whole expansion were taken up in that way; but there would be great strain on the joints, which might become leaky when the pipes were cooled. Even if metallic joints were used the compressive strain caused by the temperature would amount to very many thousand pounds per square inch, based on well-known facts as to the rate of expansion and the modulus of elasticity, and I called the attention of

my client to the fact that the separate foundations were not laterally sufficiently rigid to resist those strains, but that the weaker side would be pushed over slightly, thus throwing the engine out of line. As this was a sensitive point, and as it was desired that the engines should, above everything, work smoothly and continuously, it settled the question, and on looking over the connections it was found that the pipes could be very easily crooked and thus provide for expansion without an expansion joint.

Mr. Cartwright studies his work so carefully and adapts means to ends in so thorough a way that I regret no figures as to costs are given. This is an important omission. Some of us are making special studies on the general subject from an economic basis, in which are considered, not simply the coal consumed, the amount of labor employed and the cost of repairs, but the first cost of the plant as a whole, for the reason that the interest thereon, which is an annual expense, may under certain conditions be so great that an apparatus cheaper than another may, when all expenses are considered on an economic basis, be the best adapted for the work. I will be pleased to hear from Mr. Cartwright the cost of his building, wheel pits, head and tail races, and, in connection with them, the cost of installing the hydraulic plant, the cost of installing the steam plant, the cost of shafting, pulleys, ropes, etc., used in transmission, and it would be more complete to have the cost of the dynamos added, when, by a comparison of these facts with those known in other cases, the engineer is best able to judge of the value of the installation from a commercial standpoint.

Robert Cartwright, M. Am. Soc. C. E.—My experience in hydraulic work has been that wet brick softens the skin so the constant attrition with the brick very soon removes it, and sore fingers is the result. I always provide my men with rubber finger covers, and keep a supply on hand for use at all times. If I cannot get the rubber covers, I buy leather harvesting mittens for the purpose.

I differ entirely with Mr. Green as to the brick being only "damp." I want them "soaked." When work is laid with soaked brick with hydraulic mortar, as our President has truly said, "the adhesion of the mortar to the brick is greater than the cohesion of particles of the brick among themselves." I do not expect, in building hydraulic masonry, to run the wall up as rapidly as with dry or damp brick, as the work would be apt to "bulge," but judgment in carrying the work on enables the engineer to shift his men on the work, giving the mortar time to harden before overloading it.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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699.
(Vol. XXXI.—March, 1894.)

THE RENEWAL OF THE CHANNEL PIER OF THE CINCINNATI AND MUSKINGUM VALLEY RAILWAY BRIDGE OVER THE SCIOTO RIVER.

By MORTON L. BYERS, Jun. Am. Soc. C. E.

READ MARCH 21ST, 1894.

WITH DISCUSSION.

Among the structures damaged by the floods of the spring of 1893 was the east pier of the single-track bridge of the Cincinnati and Muskingum Valley Railway, across the Scioto River, south of Columbus, O.

In July, the writer, on taking charge as Engineer of Maintenance of Way of the Cincinnati and Muskingum Valley Railway, found that false work had been driven to relieve the pier of the weight of the bridge, plans prepared and bids requested, and he was informed that the probable cost would be about $3 500 for rebuilding.

The plan, on examination, proved to be for the ordinary design of masonry pier, resting on a foundation composed of three lines of piles driven about 4 ft. between centers, longitudinally, capped trans-

versely, and with a grillage of two solid courses of 12 x 12-in. hardwood timber drift-bolted to the caps. From base of rail to low water-mark was 28 ft. 9 ins., and to the top of the grillage foundation was 10 ft. 3 ins. additional, making 13 ft. 3 ins. from extreme low water-mark to the top of the piling, which was to be 18 ft. long in place.

At various times the river had threatened to undermine this pier, and, as a protection, a ring of piling had been driven at a distance of about 25 ft. from the pier, entirely around it, and the space between the piling and the pier had been filled with rip-rap and blast-furnace slag.

The last flood had succeeded in dislodging this material from the upper end of the pier, and had undermined the nose to some extent. When the water subsided, the pier suddenly cracked from top to bottom, and commenced to settle badly, so that it became necessary to drive temporary bents at once, to carry the two spans (one a Howe and the other a Pratt truss), of 148 ft. each, until such time as the pier could be rebuilt.

Early in July a single bid was received, and, when opened, proved to be for $8 500, much to the writer's surprise, as he had not up to this time examined the structure. On going to the bridge, to investigate into the cause of this unexpectedly high bid, the following state of affairs was found : The temporary bents carrying the two spans were arranged as shown by Plate XLIV, the bents on either side of the old pier being but from 12 to 13 ft. apart, and not quite parallel. The space between the pier and the old piling had been refilled with rip-rap and boulders of all sizes.

At a depth of about 18 ft. below low water a bed of hard blue clay appeared, while in the vicinity of the pier, and carrying it, was a mound of sand and gravel, which extended to the surface of the water and was about 80 ft. in diameter at its base. Beyond the base of this mound the water had cut, in places, entirely through the gravel and exposed the clay.

A boat had been built for use in driving the piling for the temporary bents, and proved to be 40 ft. long by 14 ft. wide—just too wide to be used in working between the bents when the pier should be removed.

It was evident that if the plan already made was to be carried out, a coffer-dam of some sort was a necessity. But what kind, and

where? It was apparent that it must enclose all the temporary bents, which would require a dam about 65 ft. square, or about 250 ft. in length, with piles at least 28 ft. in length. With the dam in place, there was a strong probability of heavy expense for pumping. Also, the removal of material by derrick and boxes would be very slow and expensive, being much interfered with by the lack of room between bents. Under favorable circumstances, it would take seven or eight weeks to obtain material, drive and pack this dam, and the excavation would require about three weeks more before the piling could be driven; so that it would be well on to the last of October before we could be sure of being out of danger from high water. This was a very important feature, as the pier upheld the channel span; the water when high struck it obliquely, forming a dangerous eddy for a coffer-dam to be exposed to, and low water after the middle of September could not safely be counted on.

An estimate of the probable cost of the work was made as given below:

Estimate of Cost of Replacing Pier—Plan A.

Removing old pier	$200 00
250 lin. ft. pile coffer-dam, at $10	2 500 00
400 cu. yds. excavation, at 70 cents	280 00
Pumping, including handling of machinery	1 500 00
27 piles in foundation, at $10	270 00
10 500 ft. B. M. grillage, at $25, in place	262 50
329 cu. yds. masonry, at $7.50 per cu. yd	2 467 50
Total	$7 480 00
Add 10% for contingencies,	748 00
Total estimated cost	$8 228 00

While it was, of course, possible, and even probable, that the work could done under this estimate, the fact remained that no contract could be made even at that figure.

To effect an economical solution of the problem, it was evidently necessary to devise some plan for dispensing with the coffer-dam entirely. With the excavation once made, the piling could be driven

and sawed off to a level with a circular saw on a vertical shaft, and a crib sunk on the piling, or very probably the bottom would be found sufficiently secure to dispense with the piling entirely, using an ordinary crib foundation. But the excavation was just what presented the difficulty.

As soon as the old pier was removed, the rip-rap and other loose material would naturally slip into the hole so made, and there was not room to remove this material till the pier was removed. So any machine used for excavating must be capable of handling such material, and also any boulders that might be encountered in the gravel itself.

A dredge small enough to work between the bents could not be obtained, and, even if it could, the work was not of sufficient magnitude to admit of the expense of transportation, or of the purchase of any expensive special tools.

Finally it was resolved to use a scraper made after the plan given in Fig. 1, and of the dimensions there given. It was made at the

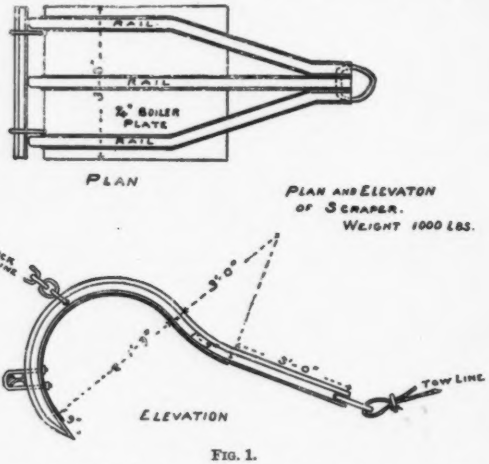

FIG. 1.

railway shops of old boiler iron, strengthened by three ribs of light iron rail, and was operated by a Mundy 20-H. P. two-drum hoisting engine, mounted on an island that had formed just above the pier. The towing-line was run direct from one drum to the back of the scraper, and the back line from the other drum over a sheave on the bridge to

PLATE XLIII.
TRANS. AM. SOC. CIV. ENGRS.
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BYERS ON RENEWAL OF A CHANNEL PIER.

the front of the scraper (see Plate XLIV), thus giving the engineer entire control of the work.

In order to allow the scraper to work, it was necessary to remove 13 of the old piles forming the upper end of the ring. The piles on either side of the one to be removed were sawed off level, and a 20-ton hydraulic jack was placed on each. Across the tops of the jacks was placed a 12 x 12-in. timber, and over it a heavy switch chain was placed, and secured to the pile to be pulled. The links of the switch chain were $\frac{5}{8}$ in., and they were tested to the utmost. Most of the piles were 18 ft. long, bedded about 10 ft. in the gravel. One was 20 ft. long, bedded 12 ft., and it broke the chain twice.

The dredging was begun on August 19th, and on September 1st a clear depth of 12 ft. had been gained over the entire foundation, somewhat over 550 cu. yds. of material having been removed. The scraper at first showed a decided tendency to upset whenever it came in contact with a piece of rip-rap, but this was overcome by bolting a piece of rail across the end, a few inches above the teeth, as shown in Fig. 1. After this was done it rarely upset, and nearly always brought out all the gravel it would hold.

The boiler capacity of the engine used proved much too small, the time required to get up steam and replenish the water being fully four times that employed in actual excavation. With proper appliances in this respect, and with the weight on the toe of the scraper, as before explained, this machine would have completed the excavation in not over three days. But even as it was, it kept from two to four men busy shoveling to one side the material dragged out. Plate XLIV shows the scraper suspended by the back line ready to let it drop for a haul-out. The material handled was not generally large, although stones weighing from 300 to 400 lbs. were sometimes brought out. The towing line used was a $\frac{3}{4}$-in. hemp-center wire rope, and the back line a $\frac{1}{2}$-in. line of the same character. Experience proved that 1-in. and $\frac{3}{4}$-in. rope, respectively, would have been better, as both of those used were completely worn out, and could not have been made to do another day's work than they did.

After reaching a depth of 12 ft. throughout, it was decided to dispense with the piling, and a crib composed of six courses of 12 x 12-in. timber, arranged four timbers longitudinally and seven transversely, so as to form three lines of pockets, each 4 x 2 ft. 6 ins., open top and bot-

tom, was built in place directly over its final position. The middle pockets were provided with slat bottoms, and filled with cobble-stones from the river bank. Two-inch tongued and grooved siding was nailed to the top course of the crib, and braced, for a coffer-dam, and the crib was sunk by placing rails on the top of the coffer thus made.

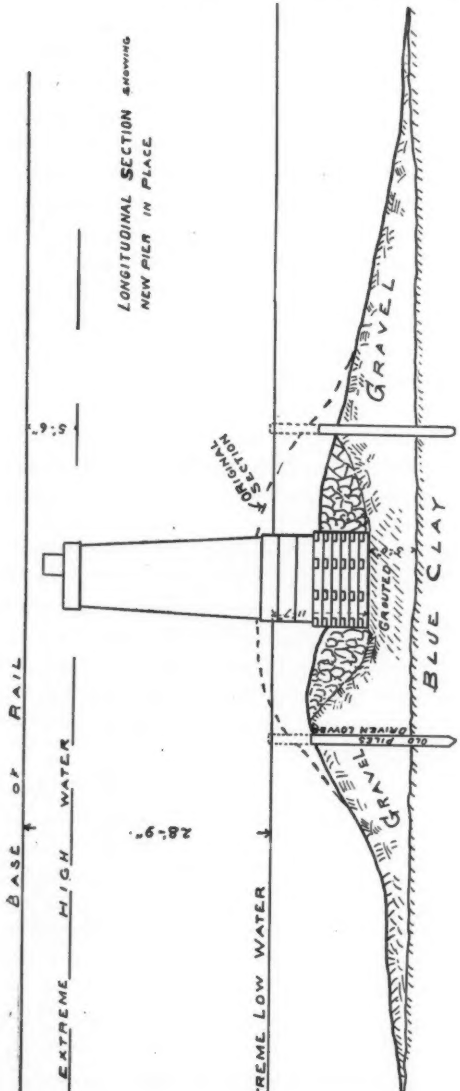
The scraper had left the floor of the excavation quite even, but to cut down all irregularities a rail 11 ft. long was dragged back and forth over the bottom. Of course, the bottom, in some places where the scraper had cut too deep, was much softer than where the gravel had not been disturbed, and it was for this reason that no bottoms were put in the outer pockets of the crib.

After the crib had been sunk it was found to be but 1 in. out of level. A slight ridge of gravel and sand was then thrown up entirely around the crib, and of such depth as to about cover the first course of timber.

In each of the outside pockets was then placed about ½ cu. yd. of rich mortar, followed by an equal amount of concrete, which latter was thoroughly rammed with an iron rammer, weighing not far from 80 lbs., with a base about 4½ ins. square, the object being to force the mortar under the edges of the crib, and also into the gravel wherever it had been loosened. The center pockets were then treated with a rich grout (it will be remembered that they were filled with cobble-stones), and the outside pockets also filled with cobble-stones and a much weaker grout. In all, 93 bbls. cement were used in the crib alone. It contained 18 pockets, each 4 x 2 ft. 4 ins. x 6 ft., 1 008 cu. ft. in all. Judging from the specific gravity of a pile of cobble-stones, one-third of this space was voids; or it required 336 cu. ft. of grout to make the mass solid. One hundred and forty barrels of sand at 3¾ cu. ft. per barrel were used, making 525 cu. ft., disregarding the volume of cement used. This would show that at least 189 cu. ft. of voids in the underlying gravel were filled by this grout.

In proof, no settlement could be detected after the third course of stone was laid, by which time the cement in the foundation had set.

In building the crib, one mistake was made, that cost about $100, and a delay of about five days. It was thought that the cement used would so close all openings in the bottom and sides of the crib as to make it water-tight, and no attempt to calk the sides of the crib was made. The writer is still of the opinion that this would probably have


LONGITUDINAL SECTION SHOWING NEW PIER IN PLACE
BASE OF RAIL
EXTREME HIGH WATER
EXTREME LOW WATER
ORIGINAL SECTION
GRAVEL
GRAVEL
BLUE CLAY
GROUTED
OLD PILES DRIVEN LOWER
28'-9"
5'-6"
18'-0"

been all that was necessary if it had been allowed to set, but unfortunately the foreman in charge became impatient, and, starting the pumps 12 hours after the grouting had been completed, soon had the crib leaking badly.

In order to avoid increasing the pumping plant, after a second attempt to fill the crevices with cement, sand and dirt were piled around the crib till the water was cut off. The water was then easily pumped out and the masonry laid. It was commenced September 19th, and completed October 11th, no especial effort being made to hasten the work after it was above ordinary low water. It may be of interest to state that the pumping plant consisted of three ordinary barge pumps.

When it was decided not to adhere to the old plans, a bid was received at the following prices, work not to be commenced for 60 days:

"For excavation to a depth of 10 ft. below low water, $3 000" (as it was carried to a depth of 12 ft. this would have been $3 600).

"For furnishing and placing all timber for crib, grillage, etc., $25 per 1 000."

"For removing and rebuilding pier, $10 per cubic yard, contractor to furnish stone."

Items of Cost.		Actual Cost.	Bid.
Removing Old Pier		$189 13	
Excavation:			
Placing engine	$51 65		
Building and placing scraper	54 30		
150 ft. of ¾-in. wire cable	26 40		
Labor excavating	208 71		
		341 06	$3 600 00
Foundation:			
Timber	$252 34		
Framing and sinking crib	113 95		
Concreting and pumping	309 40		
93 lbs. cement	74 40		
		750 09	450 00
Masonry:			
260.71 cu. yds		1 955 32	2 607 10
Total		$3 235 60	$6 655 10

It was decided, however, to proceed with the work at once, and the contract for the masonry was given to Mr. F. C. Neeb, of Lancaster, O., to whom, it is but fair to state, the writer is indebted for many valuable suggestions, the final plans being the result of a careful study

and discussion of the situation. Second-class masonry was decided on at $7.50 per yard, and the foundation was put in on force account, the railway furnishing the carpenter force.

The actual cost of the work is given in table on page 368, and to show the economy of the method employed a comparison is given, using the same quantities and the prices of the bid referred to on page 368.

This does not represent the cost of work performed under exceptionally favorable circumstances. On the contrary, the method employed was entirely new to all parties interested, the machinery, as before explained, was insufficient and unequal to the work, and the necessity for experiment before arriving at the best means delayed the work considerably.

The writer is satisfied that under similar circumstances the cost could be reduced.

If it had been so desired, the excavation could have been carried at least 6 ft. deeper with ease, and at about the same cost per cubic yard, viz., $\frac{341.06}{550} = 62$ cents.

Indeed, as $105 95 of the total of $341 06 is the cost of placing the engine and building the scraper, it is probable any further excavation would have decreased the cost per cubic yard.

In case no island had been at hand, the engine could have been mounted on a boat and anchored in a convenient spot below the pier, gaining the aid of the current, which caused some little annoyance on the work described, by carrying the finer matter back into the excavation.

DISCUSSION.

S. Munch Kielland, M. Am. Soc. C. E. (by letter).—I have read the advance copy of Mr. M. L. Byers' paper, on the removal of the pier of the Cincinnati and Muskingum Valley Railway Bridge over the Scioto River.

Mr. Byers' scraper appears to be a good construction, and ought to be a very practical tool for similar excavations.

I am not able, from the reasons given, to see why the pile foundation as suggested by the former engineer was not adopted. If the scow was too wide, it could not have cost much to have made it narrower; but, besides, the so-called island appears from the drawing to

be high enough and large enough, together with the old piles, to have been used as support for the pile-driver. Further, why was it necessary in this case to cut off piles at 10 to 12 ft. below low water? Four feet would have been plenty, which would have brought the platform 1 to 2 ft. below extreme low water, and certainly a pile foundation like this would in this case be safer than the crib which was put in. The pile foundation would require very little excavation and less masonry, the repairs could have been made quicker and cheaper, and no cofferdam would have been needed.

Morton L. Byers, Jun. Am. Soc. C. E. (by letter).—The reasons for using a crib instead of a pile foundation were briefly as follows:

Owing to the positions of the chords, floor beams, stringers and false work, the driving could not be done from the bridge. There was but 21 ft. 9 ins. clear from low water to false work carrying the pedestals of bridge. Of this space would be required, for rigging of driver, 2 ft. 6 ins.; for hammer, 3 ft.; at least 1 ft. fall to start driving, and since a 3-ft. rise could be expected at any time, that much would also have to be allowed for, making in all 9 ft. 6 ins. not available of this 21 ft. 9 ins. Assuming that the piles were to be driven 4 ft. below low water, and excavation carried but to this depth, this would give a pile 21 ft. 9 ins. 21 ft. 9 ins. — 9 ft. 6 ins. + 4 ft. = 16 ft. 3 ins. in length, which, of course, would have been entirely unsafe, as a glance at the cross-section will show. I do not consider a pile under 30 ft. in length as capable of giving a safe foundation with top at the depth mentioned. If a 30-ft. pile was used, it would be necessary to excavate to a depth of 17 ft. 9 ins. in order to get the pile in the leads of the driver.

Again, supposing the excavation made (it is doubtful if it would have been safe to excavate so deeply on account of the false work), it would have required ten days at least before the last pile could be driven, and meanwhile there would be constant danger of the excavation filling in. In this case the pile-driver would have seriously embarrassed us in using the scraper to re-excavate.

As it was, the crib was sunk and secured 36 hours after the excavation was completed.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

700.

(Vol. XXXI.—March, 1894.)

DRIVEN WELLS OF THE PLAINFIELD WATER SUPPLY SYSTEM.

By L. L. Tribus, Assoc. M. Am. Soc. C. E.

Read February 21st, 1894.

WITH DISCUSSION.

General questions, like the sanitary requirements, fire protection needs, and usual methods adopted for the supply of potable water under pressure, have been too exhaustively treated to warrant any time being given to them here. It is, however, often a matter of more or less interest to know some of the special features in particular localities; therefore, the writer, who was resident engineer during construction, ventures to offer to this Society a few notes on the construction and operation of the Plainfield (N. J.) Water Works.

These works may be classed among the "driven well" systems, of which we have comparatively little published information.

Mr. Charles B. Brush, M. Am. Soc. C. E., was Chief Engineer during construction. Mr. Amos Andrews is at present Superintendent of the company. To their courtesies the writer is indebted in the preparation of these notes.

By referring to the topographical map of that portion of New Jersey XLIV (Plate ~~XLV~~), there will be noted just east of the Plainfield water-shed (indicated thereon by broken lines) the surface evidences in the distorted contours of the termination of a glacial moraine.

The porous nature of the under strata in some portions west of this eastern boundary, with their freedom from sand or other fine materials, suggests the gravel and small boulders of the under side of such a moraine, deposited as the larger masses on top passed onward, while the varying character and positions of the strata, sand, clay and gravels at different points throughout the valley, determined by borings for private wells, verifies the surmise.

The region itself is a comparatively level valley, some 7 miles long and from ¾ to 2 miles wide, is fairly well wooded and slopes gently to the westward. It is divided by a small stream running to the southwest, having several short tributaries; together they furnish excellent surface drainage for the city.

The soil consists mostly of sand, clay and gravel strata, rock not being encountered, except at considerable depths.

It has always been an easy matter to procure water in abundance for domestic use by driving pipe wells from 20 to 80 ft. deep at each residence, and attaching pumps directly thereto; and for fire supplies, sinking large brick curbs some 15 or 20 ft. into the gravel, gave an abundant flow. But obviously, with the increasing population and no sewerage system, individual wells became a source of danger to health, yet for nearly twenty years no definite result was accomplished, more than the mere organization of a private water company.

In 1890, active measures were taken and tests and examinations made, which finally resulted in the sinking of pipe wells on a plot of ground 1½ miles east of the center of the city in a soil where the upper clay stratum was some 30 ft. or more in thickness, underlaid by a very coarse water-bearing gravel. This spot was selected for its freedom from probable contamination on ground slightly higher than the city, which at the same time was convenient.

Several test wells were sunk at various points previous to the observations of the writer, and pumping tests made with a low-lift pump of a number of the main wells then driven, under the care of Mr. Rudolph Hering, M. Am. Soc. C. E. The quantity of water obtained from ten wells for periods of eight hours' daily consecutive pumping, during

PLATE XLIV.
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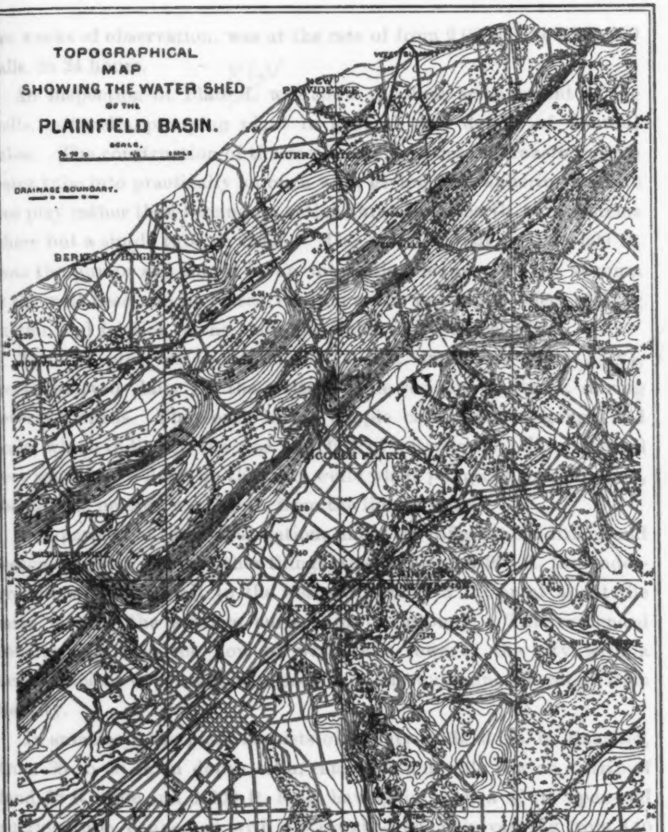


two weeks of observation, was at the rate of from 2 000 000 to 2 125 000 galls. in 24 hours.

An inspection of Plate XLV ~~L~~ will show the final arrangement of the wells, test wells, pumping plant in general, and details of the well tubes. The construction of the cast heads is such as to transform each water tube into practically an open well, giving atmospheric pressure free play rather than forcing its action through the earth, as in systems where but a single tube is used. The most distant well is 500 ft. from the pumps and shows in an interesting manner by the vacuum at the well head and increased vacuum at the pump the effect of long suction and friction in the main (see Table of Tests, page 376).

The 2-in. pipe test wells, marked A, B, C and D, on Plate ~~XLVI~~, XLV were observed daily by the writer, while resident engineer, during several months. They each had a simple balanced float-gauge and scale, which indicated the rise and fall of water-level. They were all very sensitive to draft on the main wells when pumping was going on, though the nearest was 200 ft. from the line of wells.

Comparison of these observations under the different conditions and seasons showed, among other things, that in about 1 900 ft. the underground water-level fell to the westward about 3 ft., or at about the same rate as the average surface of the ground. This evidenced conclusively that the flow of water was towards the city with a head sufficient to prevent any back flow of contaminated waters from the city.

In summary, the plant consists of twenty wells, 6 ins. in diameter, from 35 to 50 ft. in depth each, ranged in a double row on a strip of land 25 ft. wide and 1 000 ft. long, having in each a $4\frac{1}{2}$-in. open-end suction tube, connected with a wrought-iron main varying from 8 to 12 ins. in diameter. This main is in two sections, each 500 ft., connecting 10 wells.

Two compound, surface-condensing, duplex plunger pumps, Worthington make, one of 3 000 000 and one of 2 000 000 galls. daily capacity, and a boiler plant of sufficient power, with various essential small machines, are housed in a rough-stone building, slate roofed.

The water, drawn, as before stated, direct from the wells, is pumped into a wrought-iron stand pipe (situated near at hand) 25 ft. in diameter and 140 ft. high, through a 20-in. interior tube rising 5 ft. above the top. Two lower openings on this rising main, with valves operated

from the outside spiral staircase, afford opportunity for filling the stand pipe at lesser head if required.

The object of this interior tube, which was almost unique when erected, is threefold.

First.—By its fountain action, enforcing complete aeration.

Second.—Complete circulation.

Third.—To afford instant fire pressure, no matter what the elevation of water in the main tower. This is accomplished by opening a by-pass, not otherwise used, connecting the rising main and the distribution line, the city's supply being drawn regularly from the bottom of the stand pipe with pressure due to level of water in main tower.

From the stand pipe the Plainfield pipe system extends to the west, comprising some thirty miles of mains from 6 to 16 ins. in diameter, having fire hydrants spaced about 11, and valves 6 per mile.

(XLVI) Plate XLVI~~I~~ shows the "loop" or "double-feed" system adopted, dividing the city into districts, each practically complete in itself.

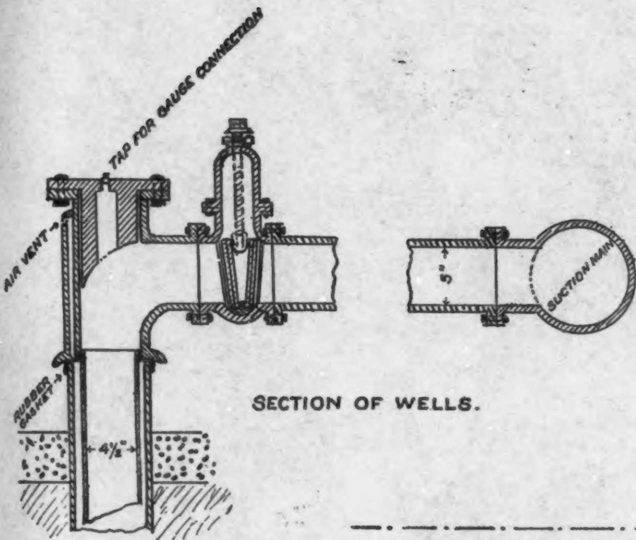
To the east lies a main running eleven miles to Elizabeth, supplying Fanwood, Westfield, Cranford, and the smaller places on the way.

Blow-offs are placed at all low points and brook crossings. Hydrant pressures range from 40 to 75 lbs. per square inch according to locality, probably averaging 65 lbs. over the whole district.

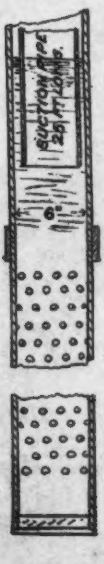
From the plan of pipe lines (Plate XLVII) a general idea can be gained of the distribution of materials and the requirements for special castings, in estimating cost of construction.

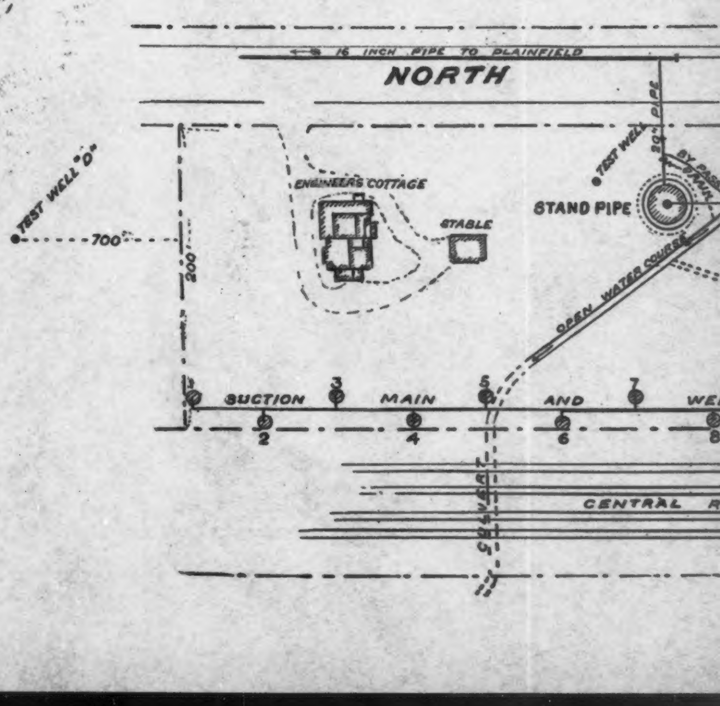
Almost all street intersections are macadamized; about two miles have Telford pavement, and three miles Macadam. On other streets by following the adopted rule of laying 5 ft. from the curb, stone pavement and Macadam surfaces were avoided. Minimum cover, 3 ft.; surface of the streets to be replaced at once in good condition. No rock was encountered in trenching, but brooks were frequently crossed, usually below their beds, but in two instances as in sketches (Plate ~~XLVIII~~). XLVII -

The cost of laying, including specials and 4-in. secondary valves for hydrants, but omitting the hydrants themselves, is given in the following table.



SECTION OF WELLS.





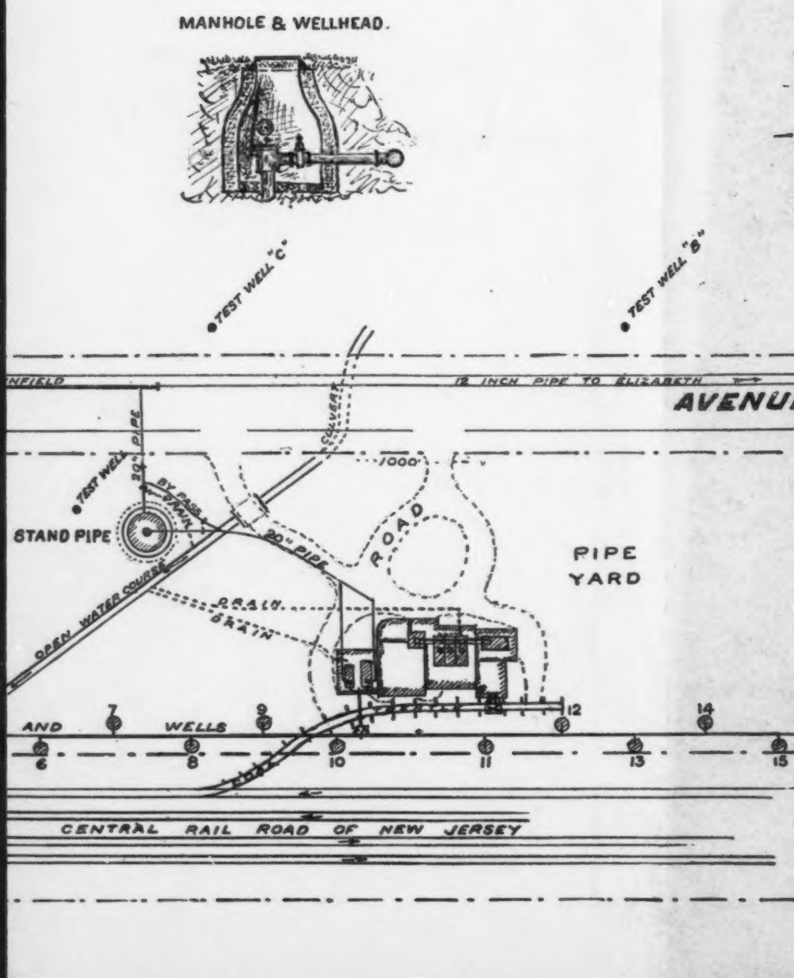

MANHOLE & WELLHEAD.
TEST WELL "C"
TEST WELL "B"
INFIELD
12 INCH PIPE TO ELIZABETH
AVENU
TEST WELL
20" PIPE
BY PASS
DRAIN
STAND PIPE
CULVERT
1000
ROAD
20" PIPE
PIPE
YARD
OPEN WATER COURSE
DRAIN
DRAIN
AND
WELLS
6
7
8
9
10
11
12
13
14
15
CENTRAL RAIL ROAD OF NEW JERSEY

PLATE XLV.
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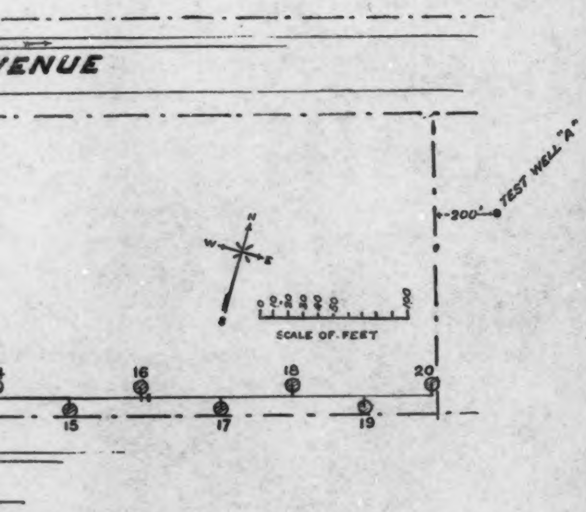
—PLAN OF PROPERTY—
—AND—
—DETAIL OF WELLS—
—PLAINFIELD WATER SUPPLY—
1891.



AVERAGE POUNDS OF MATERIAL PER LINEAR FOOT LAID.

	6-In.	8-In.	12-In.	16-In.
Pipe	30.00	44.00	76.00	124.00
Specials	0.70	0.90	1.80	3.10
Lead	0.85	1.05	1.84	2.05
Packing	0.01	0.02	0.02	0.03

COST PER LINEAR FOOT OF PIPE LAID.

	6-In.	8-In.	12-In.	16-In.
Pipe and specials	$0.394	$0.561	$0.965	$1.580
Lead and yarn	0.040	0.050	0.087	0.097
Valves and boxes	0.041	0.050	0.054	0.072
Tools and labor	0.124	0.165	0.177	0.260
Contractor and engineering	0.034	0.063	0.061	0.089
Total	$0.633	$0.889	$1.344	$2.098

But to return to the point of chief interest in these works, viz., the experiments and ultimate success of the wells. After the tests made by Mr. Hering and the partial completion of the works, various other tests were made with the permanent pumping plant. It was found that the wells on the westerly line yielded more abundantly than the easterly ones, under equally good conditions, and gave a lower vacuum for the same quantity pumped. This, taken with the observed difference of water level previously mentioned, tended to confirm the belief that the water came from an underground stream, flowing southwesterly, just skirting the eastern wells and flowing full past the western ones.

The tests were made with the large pumps, under both free discharge and full working head, singly and together, and drawing from the wells in groups of 5, 10, 15 and 20, using each combination of 5; also, by cutting off one by one until the smallest number that could be used was reached, then adding one by one in reverse order until the full series were again in use. Five wells were found to be the smallest number possible to use and run the pumps smoothly. Wells Nos. 6 to 10 gave the best results, while Nos. 16 to 20 furnished but little water. The best results were obtained for a full flow by using Nos. 1 to 15 inclusive.

The time covered by these tests ranged from 4 to 81 hours each, in several different months and with both low and high pump speeds.

From among them the following summary is given, to show approximately the relation between speed of pump, suction lift and friction loss between the observation points.

DATA.

Pump—3 000 000 galls. capacity, 24 hours.

Full speed—124 strokes per minute.

Delivery pressure—62½ lbs. per square inch.

Wells used—Nos. 1 to 10, inclusive.

Readings taken—30-minute intervals.

Length of test—24 hours, August 12th and 13th, 1891.

TIME.	Average number of strokes per minute.	Total United States gallons pumped.	Average suction lift in feet referred to level of upper pump valves. Wells. No. 1.	Wells. No. 9.	Air chamber in engine-room.
Hours.					
4	48.5	203 147	21.0	22.1	25.3
4	59.5	249 500	21.6	22.9	26.1
4	64.6	271 491	22.2	23.3	26.8
4	58.3	244 335	22.0	22.8	26.4
4	57.6	241 263	21.8	22.9	25.9
4	61.9	259 274	22.1	23.0	26.5
SUMMARY AND AVERAGE OF ABOVE.					
24	58.4	1 469 010	21.78	22.83	26.16

The following test was made to determine the maximum flow, after the works had been in service for some five months.

DATA.

Engine 634—2 000 000 galls. per 24 hours.

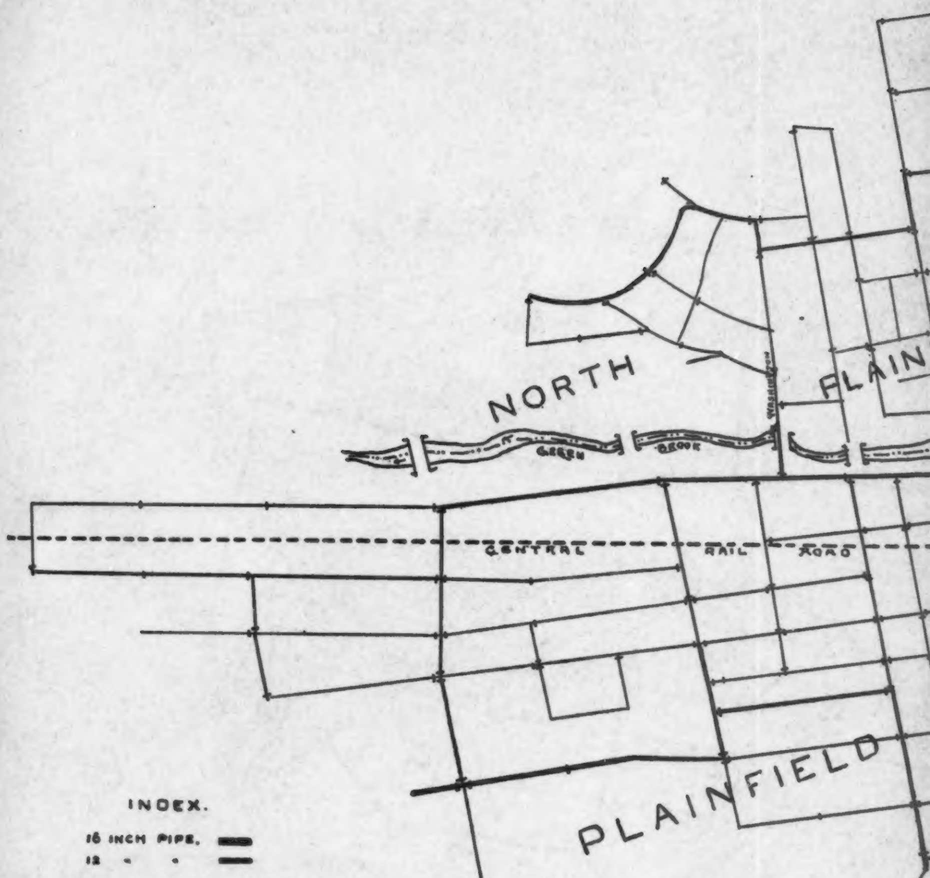
" 635—3 000 000 " " "

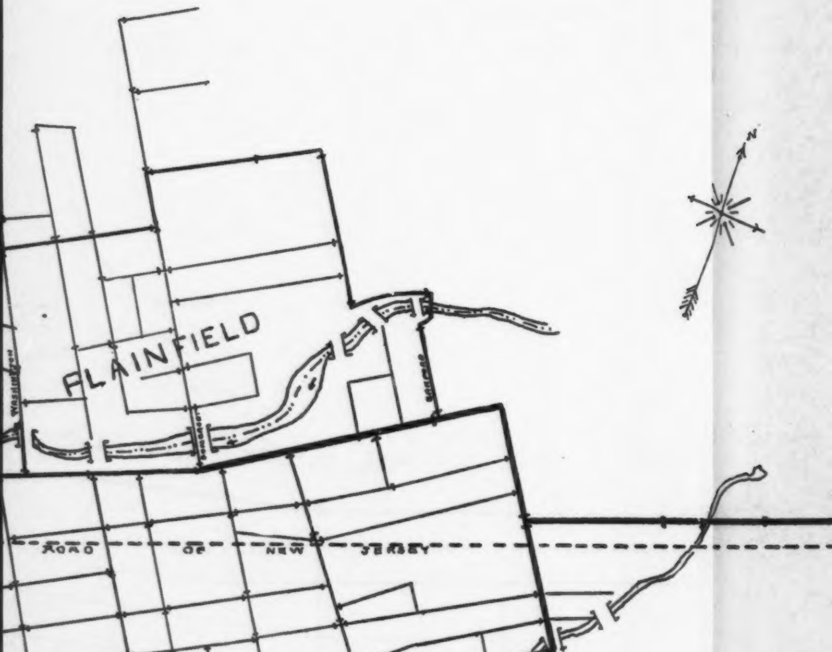
Full speed each—124 strokes per minute.

Delivery pressure—62½ lbs. per square inch.

Readings taken at three-hour intervals, uniform running.

Test made by Amos Andrews, Engineer, March 8th to 11th, 1892, before lowering of pumps.


NORTH
PLAIN
GREEN
BROOK
CENTRAL
RAIL
ROAD
PLAINFIELD
INDEX.
16 INCH PIPE.
12 " "
8 " "
6 " "
GATES.



PLAINFIELD
ROAD OF NEW JERSEY
IELD
CEDAR BROOK
N

PLATE XLVI.
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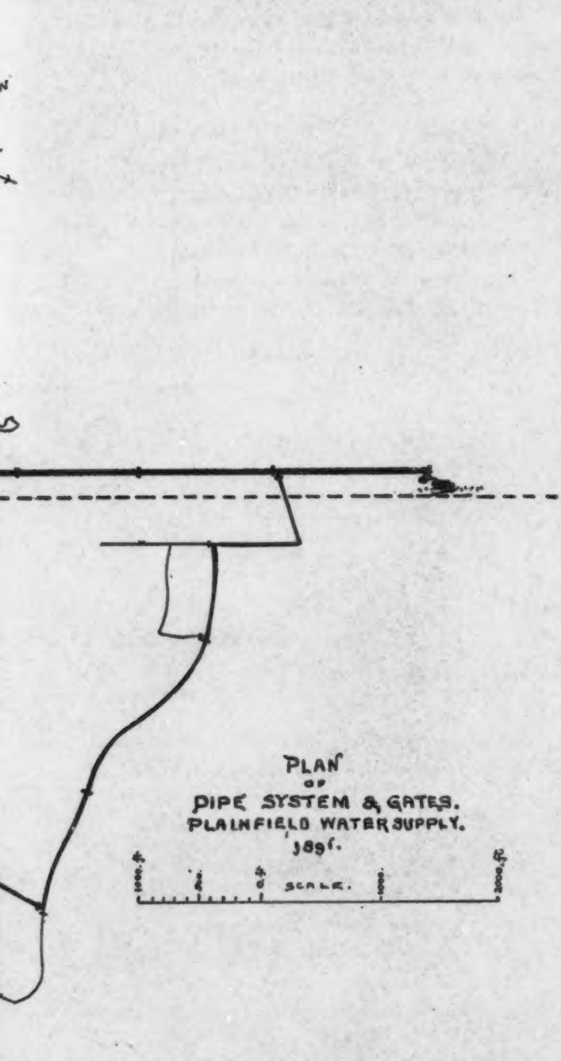
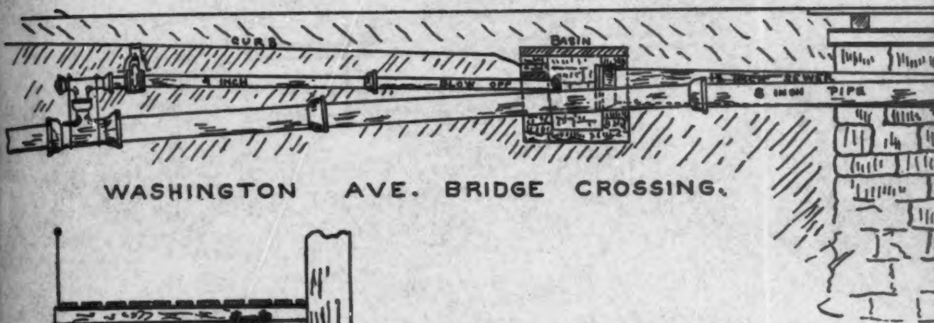
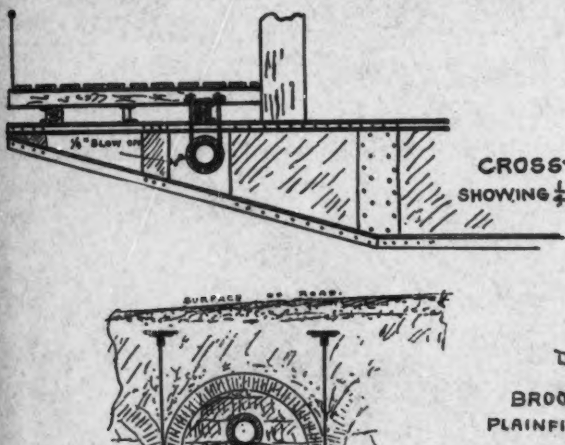


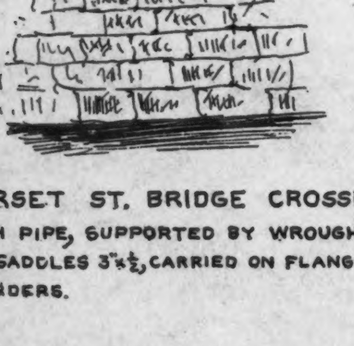


WASHINGTON AVE. BRIDGE CROSSING.



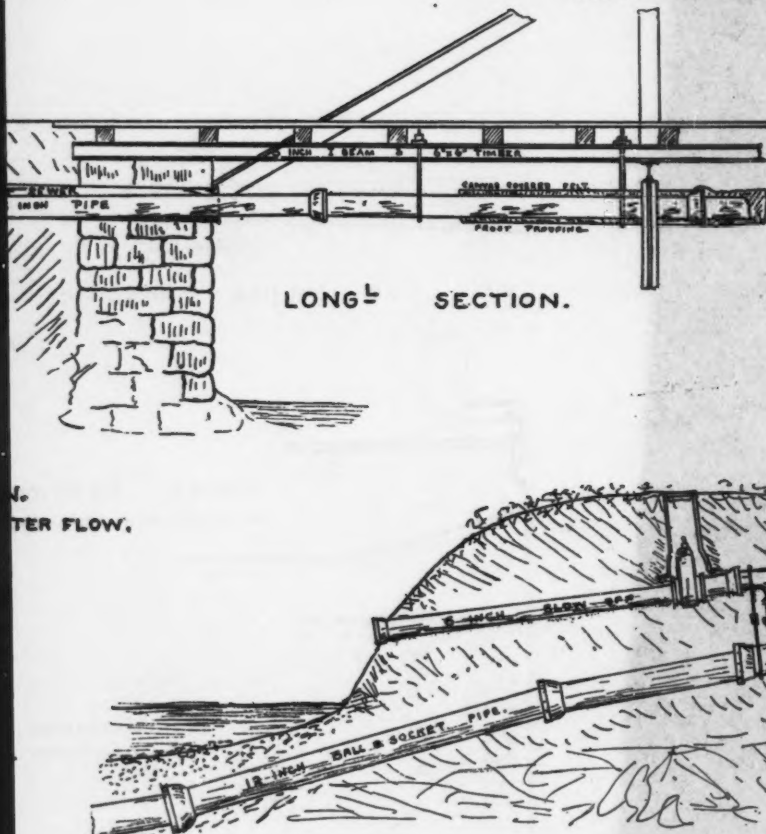
CROSS SECTION.
SHOWING ½" DRIP FOR WINTER FLOW.

DETAILS
OF
BROOK CROSSINGS.
PLAINFIELD-WATER SUPPLY.
1891.



SOMERSET ST. BRIDGE CROSSING.
8 INCH PIPE, SUPPORTED BY WROUGHT IRON SADDLES 3"x½, CARRIED ON FLANGES OF GIRDERS.

PLATE XL
TRANS. AM. SOC. C
VOL. XXXI, N
TRIBUS ON DRIVEN WELLS



SANFORD AVE. CROSSING.
12 INCH SPHERICAL JOINT PIPE.

PLATE XLVII.
AM. SOC. CIV. ENGRS.
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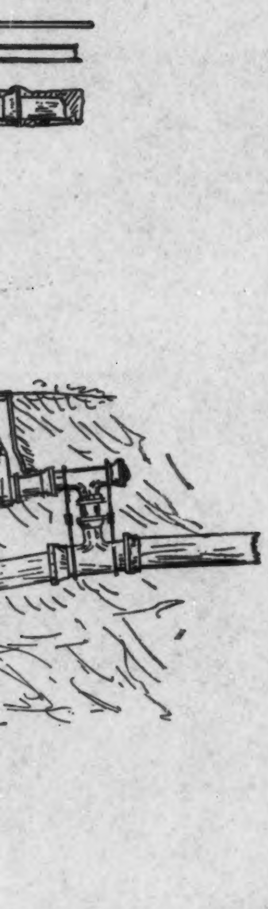
EN WELLS AT PLAINFIELD, N. J.



TIME.	Average number of strokes per minute.		United States gallons pumped each 12 hours.			Average suction in feet. Readings from gauge in suction pipe.	REMARKS.
Hours.	No. 634.	No. 635.	No. 634.	No. 635.	Total.	Air chamber.	
12	69 7	66.0	590 477	830 740	1 421 217	27.0	20 wells.
12	71.9	62.3	609 109	782 360	1 391 469	28.0	"
12	74.9	73.5	632 070	923 796	1 555 866	28.2	15 wells, 1 to 15.
12	73.4	77.7	621 813	977 340	1 599 153	28.4	" "
12	77.1	75.9	652 678	954 721	1 607 399	28.5	" "
12	82.1	76.4	695 305	960 586	1 655 891	28.6	" "

SUMMARY OF ABOVE TABLE.

HOURS.	Total United States gallons pumped.	Average suction lift in feet.	Wells in use.
24	2 812 686	27.5	20
24	3 155 019	28.3	15
24	3 263 290	28.55	15

During the long-continued dry weather of 1891, the water level became so low that difficulty arose with the extreme suction lift obtained, from 20 to 28 ft., according to rate of pumping, a fall of some 6 or 7 ft. since the earlier observations, so that in the summer of 1892 it was deemed best to lower the pumps, which was done to the depth of 8 ft. 1 in. below the former positions.

For the sake of a constant observation and record, a 3-in. open tube was driven from the engine-room, into the water-bearing gravel, and a permanent float gauge suspended in it, indicating by a balanced pointer on a scale of feet placed conveniently in the room. Although some 80 ft. from the nearest main well, therefore not showing the lowest level of the water at the wells when pumping, it does show the relative water-level under the same conditions and the daily and monthly range. When pumping, the average lowering of the gauge is about 8 ins., with an almost immediate return after stopping the pump.

Rainfalls need to be exceptionally heavy to make any marked showing in the water-level, and not much then inside of 24 hours. This seems to indicate that the water supply comes from a distance, but there is an insufficiency of data for determining this interesting point.

In these two years or more of operation, the wells have furnished daily, without difficulty or signs of falling away, the full demand of

from 200 000 galls. at the start to 1 700 000 galls. at the present time, apparently derived, as the early tests indicated, from the western fifteen of the twenty wells driven. The water itself has been of uniformly excellent quality, both for domestic and manufacturing purposes; so far, therefore, a decided success as an underground water supply.

DISCUSSION.

P. K. YATES, M. Am. Soc. C. E. (by letter).—I take this opportunity to give my experience in obtaining a supply for a system of water works by means of driven wells.

It was my privilege to design and construct a system of water works at Natchez, Miss., in 1887–89. The works were built on the franchise system, and it was especially designated that the supply should be taken from the Mississippi River.

The company was averse to taking the supply from the river, as it was found after several experiments that the water would not clarify itself after standing three days. So desirous was the company of securing pure water that would be acceptable to the people that it decided to drive wells, to determine whether a supply could be obtained in that way.

At that time the city of Memphis, some 300 miles up the river, and Bâton Rouge, 100 miles down the river, had obtained water from driven wells, and if water could be obtained in that way, it meant success for the company. At Vicksburg, about 100 miles up the river, a well had been put down in rather a crude manner without success. We knew, also, that the river water system at Vicksburg was not producing clear water, and the water was not generally used for drinking purposes.

Work was commenced on the wells, and after a few delays and trials we struck a water-bearing bed of sand 40 ft. thick and about 260 ft. below the surface. The sand was very coarse, and success was assured; the water flowed freely to the surface. Upon analysis it was found to be of a superior quality.

The manner of putting down the wells was, first, to put in a casing, thereby excluding all surface water, and then commence with pipe of

the desired size, and continue it nearly through the sand. The pipe had a notched cutting edge, and as it was made to revolve by machinery, it gradually wore its way down. Water was continually pumped down the center of the pipe, washing out all material in the center and driving it to the surface on the outside of the pipe. Hard material was sometimes encountered, when drills would be dropped down the wells and the hard material drilled away. The pipe would have to be pulled up occasionally, to put on a new cutting edge; hydraulic jacks, connected with powerful pumps, were used for this purpose. In one case the pipe was pulled apart, which necessitated starting a new hole.

After the pipe was in place, the strainer—about 30 ft. long—was dropped into it, and it was then pulled up 30 ft., the strainer remaining in the sand. A patented connection prevented the water getting into the pipe except through the strainer. The wells were a complete success. The pumps were lowered six ft. below the surface of the ground, so the water flowed freely to them.

The supply was more than sufficient for the capacity of the pumps, and continuous pumping had little effect in lowering the water in disconnected wells.

The works were finally completed, and the day set for testing the pumps. They threw the required six streams through 50 ft. of 2½-in. hose 100 ft. high, and the works were presented to the city for acceptance.

So prejudiced was the Board of Aldermen against this new method of obtaining water that it refused to accept works with this source of supply. The Board sent samples from the wells to three leading chemists of the South, together with samples from the river, and, although the results were favorable to the well water, it was only after every physician in the city had declared in favor of the latter that the Board decided to yield to the company. The experience of this company was no doubt similar to that of many others; it was asked to do something which it knew would not be beneficial to the company or to the city ; it was willing to incur the expense of determining whether water could be obtained from driven wells, and, having obtained a good supply, was not willing to abandon it. In my opinion this contest was perfectly legitimate.

It may be of interest to say that not one family in the city used river water to drink. Their drinking water was obtained from cisterns.

Many families have two or three cisterns which are all underground. They are about 16 ft. deep and 10 ft. in diameter, and hold about 9 000 galls. If the cisterns are well cleaned, the water caught only during the winter season, and care used in keeping the roofs clean, it would be hard to find purer water. In the majority of cases, however, there is only one cistern holding about 5 000 galls. of water, the conductor from the roof is connected with the cistern winter and summer, and no great care is taken in keeping the roofs clean. It can be readily seen in what condition the cistern would be after one year's use.

Charles B. Brush, M. Am. Soc. C. E.—As has been stated, these works were commenced by one company and finished by another. A mistake has been made in the statement as to the connection of Mr. Hering with the work; he was not employed by either company, but he was an expert appointed by the city to pass upon the work as it was constructed by the first company. When I was called in, the wells had been driven by F. W. Miller, of New York City, and had been found to be in a satisfactory condition. The foundations and the walls of the pump-house had been built, and the results of the investigation made at that time indicated that the better thing to do was to go on and finish the work as it had been accepted at that time.

The year in which the work was done was a wet one; there had been a considerable fall of rain and it was believed that the level of the water in the ground would remain practically constant, but the first year after the supply was put into use happened to be very dry. That indicated that this supply was not inexhaustible. The groundwater fell to a considerable depth below what was supposed to be its permanent level. That necessitated the lowering of the pumps some 8 ft., after the works had been in operation a couple of years. The supply has been very satisfactory. The quality is all that could be desired, and the quantity has held out remarkably well.

One of the important features, it seems to me, of this supply, is one that has been referred to by Mr. Tribus, that is, as to its aeration before its delivery. All waters taken from underground sources deteriorate rapidly if they are allowed to stand any length of time, and therefore it is desirable to aerate them as much as possible, and this was very successfully accomplished by forcing the water through an interior tube in the stand pipe. There have been, so far as I know, none of the difficulties from algæ and similar troubles that we often

find in underground supplies on Long Island and elsewhere. I think this is largely due to the fact that the water is kept so constantly in motion, and because there is an absence of the low elevations of water which we find on lower levels along the sea coast. The elevation of the water in the Plainfield wells, above tide water, is considerable.

Mr. Tribus.—The water level at rest is about 106 ft. above sea level.

Mr. Brush.—I think that accounts for the fact that we do not have the difficulties in these wells that we find in water taken from lower levels near tide water.

The literature on the subject of water taken from subterranean sources is not large, and I think that papers of this kind which describe actual experience, the difficulties and the methods of overcoming them are exceedingly important. The more carefully written papers we can obtain on this subject, the better it will be for the profession.

I submit the following data from memory, but let it be understood that these wells were all completed and accepted before I had anything to do with them. If you will turn to the diagram you will notice that 20 wells are shown on a line of pipe 1 000 ft. in length.

When the tests were being made as to the amount of water that could be obtained from the wells it was found that, as stated in the paper, the natural difference in level between test well *A* and test well *B* was about 3 ft. fall towards the City of Plainfield. Taking that as the normal condition of the water, at the time of pumping, the water was actually lowered in well No. 9 about 3.1 ft. In the test well in the house, which was not connected at all with any other wells and which was opposite the line between wells Nos. 10 and 11, the water in that test well was lowered about 14 ins. The water in test well *A* was lowered 8½ ins.; in test well *B*, 8 ins.; in test well *C*, 7½ ins; in test well *D*, 7 ins. You will notice that test well *A* is about 200 ft. from the eastern well of the series; test well *C* is about 300 ft. from well *B*, and test well *D* is about 800 ft. from well No. 1. Of course there were not a sufficient number of these test wells, at least when I was connected with the work, to determine exactly the nature and extent of the cone as completely as would be desirable to show it, but the data were sufficient to get an approximate idea of the extent and influence of the cone from the data which I have submitted to you. I would suggest that Mr. Tribus give the additional data asked for during the discussion.

A. S. TUTTLE, Jun. Am. Soc. C. E.—The water supply system of Brooklyn, N. Y., offers an illustration of driven wells operated under what may possibly be considered ideal conditions, since a large portion of the water-shed offers no ready surface drainage, and the sandy soil favors an underground storage, while the uniformly low elevations fail to afford site for other than shallow storage reservoirs, and these at great cost.

The total average daily consumption of water is about 75 000 000 galls., of which amount approximately one-third is supplied by driven wells located at five different points in the water-shed area. The driven well plants have all been constructed under contract to furnish the city with a given quantity of water; it can therefore be readily understood that no more wells were driven than were necessary to deliver the required amount. An unexpected interruption of a portion of the city supply of surface water about a year ago developed a peculiar case, in that two of the stations, after having been in operation for nearly eight years, proved their ability each to deliver 10 000 000 galls. daily instead of 5 000 000 galls., for which they were designed, and one of these plants has since continued to deliver the larger amount.

Mr. George H. Andrews, of the firm which built these plants, has advanced the theory that the continued use of driven wells opens the water-bearing strata, reduces the friction, and so affords more opportunity for the water to reach the wells.

A popular and widespread idea seems to exist that to sink wells anywhere on the southern slope of Long Island insures an almost unlimited supply of water of the finest quality, so that it may be well to state here that the common experience of those who have ventured in that field has proved that the locality in question fails to differ from others in this respect, and that the subsoil water has sought out its own channels, which must be located before a permanent and substantial yield can be expected.

Theory in regard to an underground supply in any locality is unsafe until it has been fully tested. In 1854, when Brooklyn was seeking advice as to the best and most economical method of securing water, an apparently exhaustive examination and report was made by J. S. Stoddard, C. E., on the subject of deriving a supply from wells. Mr. Stoddard concluded that the underground water was evenly dis-

tributed over the entire area, and that since the surface of the same on the southern side of the island showed a slope of 10 ft. per mile toward the sea, such a slope would be necessary to cause the flow through the underground strata; from this, as a basis, and assuming that the hydraulic grade line to the wells would have a uniform slope of 10 ft. per mile, the conclusion was reached that, if a well be sunk 10 ft. below tide and at a distance of one mile therefrom, it would receive salt water, and in like manner a well in the center of the island, where the width is 10 miles, could not penetrate more than 50 ft. below tide water, or it would become brackish. The fallacy of the theory is established by the fact that some of thedriven wells are operating at depths of 350 ft. below tide, and located less than 3 miles from salt water.

The deep wells usually have strainer joints inserted at various points in their length, so as to drain from the different water-bearing strata encountered, the surfaces of which may be at different depths all the way down to the bottom of the well.

In regard to the effect of pumping upon the underground water level, there was some time ago an article in *Engineering News*, by Prof. Trowbridge, which stated that numerous experiments made at one of the pumping stations showed that at 4 300 ft. from the wells the water was lowered 6 ins., at 2 300 ft. it was lowered 2 ft. 2 ins., and at 300 ft. it was lowered 4 ft. 8 ins.

At one of the stations, consisting of 150 2-in. wells driven to an average depth of 80 to 90 ft., the soil is naturally saturated to within a foot of the surface; but when pumping 5 000 000 galls. daily it is reduced at the wells about 12 ft., and when 10 000 000 galls. are pumped per day, it is still further reduced about 3 ft.

Mr. Andrews has stated that his experiments have fully proved that the water level on the southern side of Long Island is not affected outside of a radius of 1 000 ft. from the wells.

W. Kiersted, M. Am. Soc. C. E. (by letter).—There are, among others, one or two points brought out by the paper of Mr. Tribus, which I should like to discuss.

1. *The Resistances in the Suction Pipes.*—It is a well-known fact, whenever water is continuously drawn from a well or a system of wells, that a hydraulic slope of the ground-water is established, falling toward the well or center of draught, the profile of which in any vertical section is an irregularly curved surface. The head which induces and

maintains the flow into the well, regardless of that causing the natural flow through ground, is the difference of level between the natural surface of the ground-water and that in the well. This difference of level in a system of driven or bored wells, whether of the single or double tube kind, depends upon the vacuum produced by the pump in the suction pipes, and it naturally follows that the nearer the pumps and suction pipes are placed to the natural level of the ground-water, and the less the frictional resistance in the suction pipes, the greater, for any given vacuum, will be the static head causing the flow of water into the wells. Now, the resistance of flow through the voids of the water-bearing sands is too great to allow any of the available head to be consumed in unnecessary resistances in the suction pipes and in the pump-lift above the natural surface of the ground-water; therefore, in my opinion, it becomes essential to locate the pumps and suction pipes very near or even below the natural level of the ground-water at the time of construction, and to so proportion the size or sizes of the suction pipes that there will result but little frictional loss.

Although this method is not usually followed and may cause additional cost in the original construction, it will, I am sure, in nearly every case, be found economical in the end, since there is a tendency to a gradual depression, within limits, of the average natural water level within the area affected by draught, to a filling of the voids of the sand around the well strainers and to a general increase of frictional resistance to flow by corrosion of the pipes, which, if the pumps and pipes are not low enough in the ground, will cause a serious falling off of the water supply and a consequent extension of the well system. Besides there is good reason to anticipate annual fluctuations of the average ground-water level as the result of occasional droughts, just as was experienced in Plainfield when it was found necessary to lower the pumps about 9 ft. The inconvenience of putting engines and pumps deep in a pit can be largely overcome by using vertical pumping engines, which are far better adapted to this character of work than are the cheaper horizontal pumping engines.

The usual practice of gradually diminishing the diameter of the main suction pipe as it recedes from the pump, even to diameters of 8 and 6 ins., can, I believe, be improved by making this pipe large and with but slight changes, if any, in diameter; since it will thus reduce the labor of the pump in maintaining an effective vacuum, and

each well will discharge into it as into a conduit through which a comparatively large body of water is moving with a slow velocity.

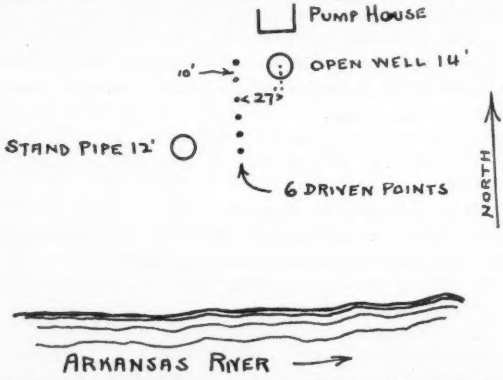
2. *The Distribution of Wells.*—The proper spacing of wells is largely affected by the coarseness and depth of the water-bearing sands. The coarser the sand, the greater the area influenced by the draught of each well, and the more widely should the wells of the system be separated. Nothing is to be gained by too thickly clumping the wells.

In an investigation and test, recently made, of a system of bored wells furnishing the water supply of a town of over 3 000 inhabitants, I found 17 wells, 3 to 6 ins. in diameter and 45 ft. deep within the circumference of a circle 125 ft. in diameter, ranged along a suction pipe 10 to 6 ins. in diameter. A pump test developed the fact that seven wells would furnish as much water as the 17. By means of test wells sunk to the same depth as the supply wells, I found the ground-water table to be depressed 0.2 to 0.3 ft. at a distance of 400 ft. from the wells of maximum draught, and 2 ft. at a distance of 95 ft. The water flowed very freely through a bed of clean coarse quartz sand and gravel about the size of a small pea. In this instance a much wider distribution of wells was necessary.

Tests made previous to the construction of a well system, similar to those made by Mr. Tribus, are essential before a proper arrangement of wells can be decided on.

It is a great advantage to have wells arranged symmetrically with reference to the main suction pipe, both with respect to distance and size of wells, since a more regular and evenly distributed flow of the ground-water follows.

H. V. Hinckley, M. Am. Soc. C. E. (by letter.)—If drive wells are large and perforated for a considerable length, there is, of course, a



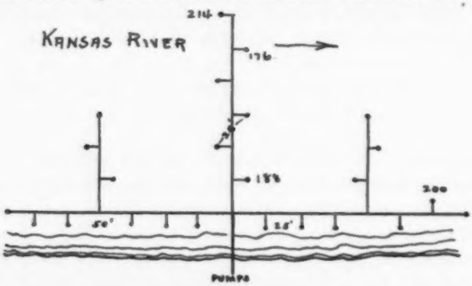
minimum distance at which they should be spaced. While the character of the water-bearing stratum must be a determining factor, I think 40 or 50 ft. may be roughly taken as the best distance.

At Great Bend, Kan., the superintendent of the city supply, attempted to increase it by adding six drive wells, 10 ft. apart. They are 72 ft. deep. They go through 30 ft. of clay, and have 12 ft. perforated at the bottom. Diameter, 4 ins. I recently tested these, and found that the maximum supply from one drive point was from 200 to 220 galls. per minute, while all six would only furnish 422 galls. per minute. In other words, Nos. 1 and 6 will furnish as much as all six.

The sketch on page 385 shows their location (scale, 100 ft. to 1 in.).

The tests for maximum supply at Plainfield show, for 15 wells, 148 galls. each per minute, and for 20 wells 97 galls. each per minute.

The new water supply at Topeka, Kan., includes 24 drive wells, 6 ins. diameter, 30 ft. deep, driven in the sand bed of the Kansas River to bed rock. Each well furnishes from 176 to 214 galls. per minute. No test has been made to determine the capacity of whole plant, but there is no doubt in my mind that after one hour's pumping one half the wells will give the same amount of water that the whole 24 will.



JOHN W. HILL, M. Am. Soc. C. E. (by letter).—Driven wells as a source of public water supply are largely used in the West. In many localities this is the only available source, and usually it is the least expensive method of procuring a supply of water sufficient for the necessities of a small community.

The city of Dayton, O., with a population of 80 000, draws its entire supply from a system of driven wells penetrating the gravel banks of Mad River from 35 to 40 ft.

The yield of driven wells depends upon the porosity, extent and depth of the pervious strata tapped. If the sand or gravel which constitutes the water-bearing strata is quite open, and free from soil or clay, and the area of the water-bearing bed is large, then such sources are more certain through the seasons than many of our smaller streams. There are many instances in the West of the complete failure of neighboring streams while the yield of driven wells has continued without material diminution during the dry period, although continuous pumping will usually show a gradual lowering of the level of the ground-

water. But as the water level is lowered, the grade of inflow to the foot of the well is increased, and the more remote portions of the pervious strata made tributary to the wells. As a rule, a system of driven wells will maintain the daily supply during drouth, excepting in those instances where the water field tapped is small in extent.

In locating driven wells near a city to be supplied with water, a good knowledge should always be had of the dip depth and covering of the water-bearing strata.

Instances are not rare where such wells have intercepted the subsoil drainage of the town to be supplied. Chemical analysis of water samples from test wells may not at once reveal the danger, while the steady pumpage will eventually train the seepage or leaching from cesspools and privy vaults into the water field.

The common belief that water from driven wells is always safe for drinking purposes is sometimes at fault. Typhoid fever has been traced to such wells, the germ having traveled from a neighboring infected privy vault through many feet of porous soil and finally finding an outlet to recommence its ravages through the driven wells.

In this connection it may be well to remark that pathological bacteria have been known to grow through the tubes of Pasteur filters. The germ becomes attached to the outer surface of the tube and by growth and fission will in due time appear on the inside of the tube and be found in the filtered water. Many of the pathological bacteria are as small as $\frac{1}{30000}$ of an inch in diameter, and can penetrate what would (excepting under the microscope) appear to be a solid substance. To remedy this evil, with Pasteur filter tubes, each time these are cleaned they should be boiled for 30 minutes, and then kept in an oven at 250° to 300° Fahr. for 30 minutes more, and sterilized so far as germs in the pores are concerned. Boiling alone cannot be depended on to kill all disease bacteria. In fact, absolute immunity from these can be had only with a degree of vigilance which it seems at all times almost impossible to exercise, or the exercise of which in the ordinary routine of life seems to be prohibitory.

In our homes it is not difficult to guard against the introduction of disease germs through our drinking water, but when we leave our homes and brave the drinking water of hotels and restaurants, then danger begins.

Who can say what kind of water is served in our public resorts, or, if the water be passed through a good filter, how are we to be assured that no disease germs or their spores are not locked up in the lump of ice with which the water is cooled? The filters used by our hotels and public dining-rooms are either incapable of removing all disease bacteria from a polluted drinking water, or the slovenly manner with which they are operated defeats this capacity (if it ever existed) in the ordinary sand and alum filter.

In the majority of cases water from driven wells is safe from a sanitary point of view. Surface drainage can reach wells only after an amount of natural filtration which will remove all the organic matter in suspension and the greater part of that in solution, and generally surface water is not to be regarded as dangerous after it has passed vertically through 35 to 100 ft. of drift above the lower ends of driven wells.

If, as sometimes happens in selecting sites for driven wells, the material overlying the water-bearing strata is very loose or consists of loam or gravel, surface water may find its way along the casing pipe to the foot of the well and introduce an element of danger, provided such surface water contains pathological germs or organic matter.

The late Mr. J. C. Hoadly undertook to develop an equation for the yield of driven wells from certain known data, but the extent of the water-bearing strata (generally unknown), the coarseness or fineness of the pervious material holding the water, and the relative amount of soluble soil in the interstices of the sand and gravel, all have such a strong influence on the yield of such wells that no rule can be capable of general application. If such wells are driven and tested at the end of the dry season and are found after several days' uninterrupted pumping to maintain a certain minimum water level (usually shown by a vacuum gauge on the suction main) the daily safe capacity for the wells can be stated with tolerable exactness.

A knowledge of the several borings for a system of driven wells is very valuable as affording the means of determining the probable capacity of such wells, provided the water-bearing strata tapped is large and capable of maintaining a constant supply equal to the requirements of the community to be served. Thus, if the water field is prospected and known to be of large extent, and the porous strata is open, as at Plainfield, a system of driven wells can be depended on for a large daily supply, but if the pervious strata consists of fine sand, while it may be very large in area, the water will come to the wells at such a slow rate as to make the yield or capacity per well very small, notwithstanding the field tapped may contain water sufficient for a large daily consumption. In such cases it is advisable to drive many wells of small diameter over a large area.

I have projected and tested quite a number of systems of driven wells for public water supply, and have found the conditions affecting the water yield to vary so much that a test of each system by pumping continuously for several days, and a careful survey of the water field, seem to be absolutely essential to an estimate of the probable capacity of such wells.

R. Willard Ware, M. Am. Soc. C. E.—I have been much interested in the subject under consideration, and am very glad that Mr. Tribus has presented the case so fully and clearly and given statistics and

data that are exceedingly valuable, and that probably could not be obtained from any other source. I think we can fully appreciate the value of the paper prepared by Mr. Tribus.

As a resident of Plainfield, I am interested in its public improvements, and particularly in its water supply. We were without city water works till within about two years. We now have a good supply of the best water known in the State for domestic use, and a pressure of 70 lbs., which may be increased to the full pump pressure for fire protection.

Judging from the numerous tests made and the amount pumped during the past year, together with the comparative heights of water in test wells, it is believed there is an ample supply of water, not only for Plainfield, but a surplus to spare for the neighboring cities and boroughs between Plainfield and Elizabeth.

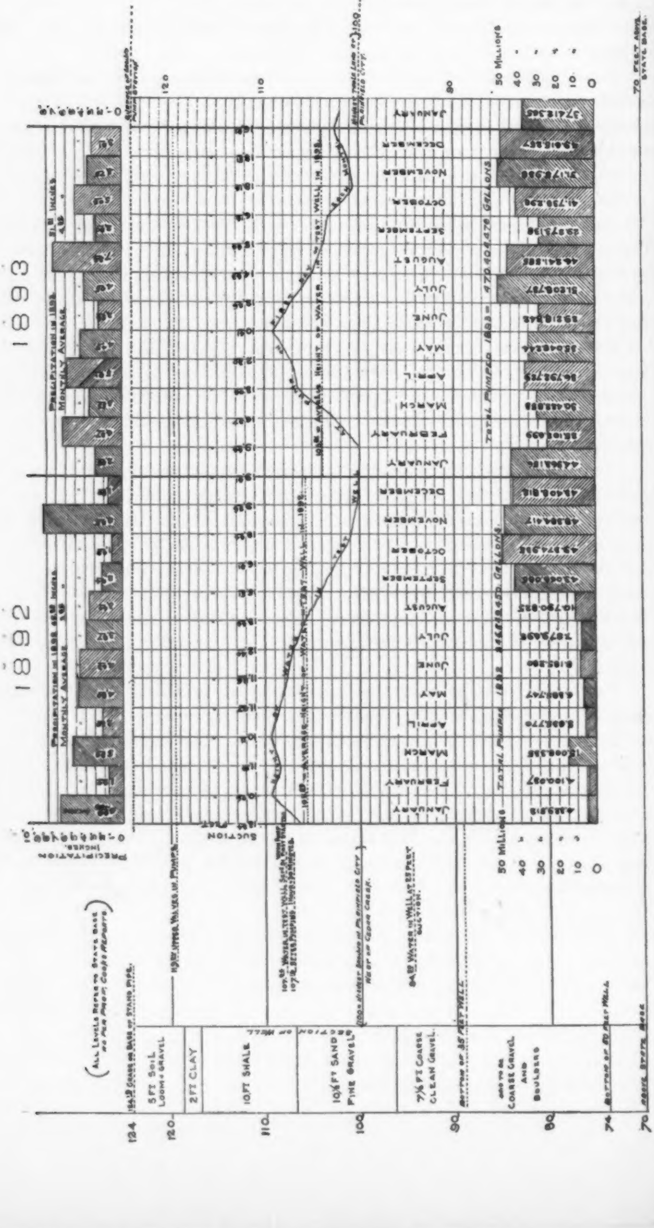
Should the water company at any time realize that the supply at the pumping station becomes inadequate to the demands, auxiliary wells may be put down at some distance from the station and operated inexpensively by the power plant that is now provided for the present station.

It is therefore believed that Plainfield's future requirements are not jeopardized by the Water Supply Company extending its water mains to supply our neighbors at the present time. Some questions have arisen in my own mind for the solution of which I have prepared a chart of the facts obtained regarding the pumping station; showing section of fluctuations of height of water in test well in pump house; suction lift of pumps; amount of water pumped monthly and annually; also, the precipitation monthly and annually in 1892–93 (see page 390).

The levels given on chart or referred to are all based upon the State datum, as per Prof. Cook's reports and contour maps of New Jersey.

Samples of material through which wells were driven show, first, 5 ft. to be soil, loam and subsoil; then 2 ft. of clay; below that 10 ft. shale; then 10½ ft. sand and fine gravel; then 7½ ft. coarse gravel, from which all sand appears to have been washed out—this being a good water-bearing stratum. This takes us to the depth of the 35-ft. wells. Samples below this depth not obtained (said to be coarse gravel and boulders).

Elevation of surface of ground at pump station	124
" " bottom of 35-ft. well	89
" " upper valves in pump engines	119.50
" " base of stand pipe	124.19
" " top of stand pipe	264 +
" " highest ground in Plainfield west of Cedar Creek	100


1892
1893
5 FT. SOIL LOAM & GRAVEL
2 FT. CLAY
10 FT. SHALE
10½ FT. SAND & FINE GRAVEL
7½ FT. COARSE CLEAN GRAVEL
COARSE GRAVEL AND BOULDERS
BOTTOM OF 35 FEET WELL
BOTTOM OF 50 FEET WELL
ABOVE STATE BASE
50 MILLIONS
TOTAL PUMPED 1893 = 470,404,476 GALLONS
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

As the pumps now stand 144.69 ft. lower than top of the water tower they work against about 62½ lbs. static pressure when the tower is filled.

It has been ascertained by careful observation, and is a matter of record interesting to notice in this connection, that the coal (fuel) consumed in pumping is 1 lb. for 300 galls. pumped into the system under a constant pressure of 62½ lbs. per square inch, the net cost of coal being $2 95 per long ton (2 240 lbs.).

One ton of coal pumps 672 000 galls., or a cost for fuel of $4 39 per 1 000 000 galls. This is the cost at the present cost of coal; it has been purchased at a lower price, so that the expense for fuel was, until quite recently, $3 95 per 1 000 000 galls.

I take pleasure in acknowledging the courteous treatment received from Mr. Amos Andrews, Superintendent at the works; Messrs. Dunham & Gavett, City Engineers of Plainfield; and Mr. John Neagle, Observer and Reporter for the State Weather Bureau.

L. L. Tribus, Assoc. M. Am. Soc. C. E.—In the course of oral discussion on this paper, a desire for further information from the note book of the author was desired.

I take pleasure, therefore, in adding certain more detailed notes, and a few not at first included or contemplated.

Among the elevations should be noted the following (above sea level):

Streets at center of the city	100
Surface at pumping station	122
Water level at pumping station	106
Upper valves of pump (old position)	126
" " " (new ")	118
Flow line of stand pipe	262

Examination of existing scattered private wells by Mr. Hering indicated the advisability of running the wells in a northwesterly line from the pump-house site, intercepting the underground flow, which seemed to be in a generally southwesterly direction. But other reasons of convenience and policy determined the placing of the wells in a southwesterly direction instead of northwesterly, with the result mentioned in the paper, of but a partial intercepting of the flow.

Referring to the tests of the wells, it was found that when they were used in small groups, they yielded more water relatively than when all, or nearly all, were under suction, except that the increased number of wells gave a decreased suction lift.

But for the latter important fact, the results would imply that a lesser number of wells than twenty, more widely separated, would have produced an equal amount of water; in that case, however, the greater friction in longer suction lines would probably have destroyed such advantage.

Mr. Kiersted and Mr. Hinckley have both contributed interesting items on this point, and the following record of experiments at Plainfield still further illustrates it.

Experiment Number.	Wells in Use.	Rate of Flow in Gallons per 24 Hours.	Total Suction Lift in Feet.	Average Gallons per 24 Hours per Well.	Wells' Number.	REMARKS.
1	10	1 470 000	26.2	147 000	1 to 10	August 12th–13th, 1891, 24 hours' run.
2	5	1 131 190	27.0	226 240	6 to 10	October 13th–14th, 1891,
3	6	1 172 000	26.7	195 330	6 to 11	20 minutes' pumping on
4	7	1 283 600	26.7	183 370	6 to 12	each combination of
5	8	1 158 300	27.2	144 800	6 to 10 + 18 to 20	wells in Experiments
6	8	1 361 500	26.6	170 190	6 to 13	Nos. 2 to 24.
7	9	1 129 500	27.3	125 500	East Group.	Varying combinations.
8	9	1 327 620	26.6	147 510	6 to 14	
9	10	1 137 970	26.8	113 790	6 to 10 + 16 to 20	
10	10	1 254 810	27.3	125 480	11 to 20	
11	10	1 400 440	25.5	140 040	6 to 15	
12	10	1 615 500	28.4	161 550	1 to 10	
13	11	1 151 510	26.3	104 680	6 to 10 + 15 to 20	
14	11	1 329 320	26.2	120 840	6 to 16	
15	12	1 185 380	26.0	98 780	6 to 10 + 14 to 20	
16	12	1 417 380	25.5	118 110	6 to 17	
17	13	1 254 810	25.6	96 520	6 to 18	
18	13	1 259 890	26.2	96 920	6 to 10 + 13 to 20	
19	14	1 219 250	25.3	87 090	6 to 10 + 12 to 20	
20	14	1 437 220	26.2	102 670	6 to 19	
21	15	1 327 620	25.1	88 510	6 to 20	
22	15	1 442 770	25.6	96 180	1 to 15	
23	16	1 700 170	26.4	106 250	1 to 16	
24	20	1 338 590	25.0	69 430	1 to 20	
25	10	2 040 390	28.4	204 040	1 to 10	October 23d, 1891, 20 min-
26	10	1 763 980	28.0	176 400	1 to 5 + 11 to 15	utes' pumping on each
27	10	1 432 290	28.8	143 230	1 to 5 + 16 to 20	group. Experiments
28	10	2 085 620	27.9	208 560	6 to 15	Nos. 25 to 35.
29	10	1 809 220	27.0	180 920	6 to 10 + 16 to 20	
30	10	1 427 270	27.9	142 727	11 to 20	
31	15	2 377 110	26.9	158 470	1 to 15	
32	15	1 789 113	27.6	119 270	1 to 5 + 11 to 20	
33	15	1 879 574	27.3	125 305	1 to 10 + 16 to 20	
34	15	1 774 030	28.4	118 270	6 to 20	
35	20	2 000 200	27.9	100 010	1 to 20	
36	15	3 210 000	28.4	214 000	1 to 15	March 8th, 1892.
37	20	2 800 000	27.5	140 000	1 to 20	

It will be noted, perhaps, that in the preceding record but rarely did wells Nos. 1 to 5 appear in use, the reason therefor being, that earlier tests had developed their satisfactory conditions, as also was the case with Nos. 6 to 10; but these latter were used to furnish a sufficient volume of water to work on while testing wells Nos. 11 to 20. Nos. 17 to 20 were found to be almost worthless.

The experiments showed that after continued operations the wells yielded relatively more water in the later tests than in the earlier without a corresponding increase in suction lift, a fact due, no doubt, to the opening up of the underground channels leading to the wells.

Regarding the range of susceptibility of water level to pumping, tests of such level shown in Figs. 1 and 2 fairly illustrate the average

results under regular operation, but observations were not taken from enough points to demonstrate with scientific precision the radius of effect.

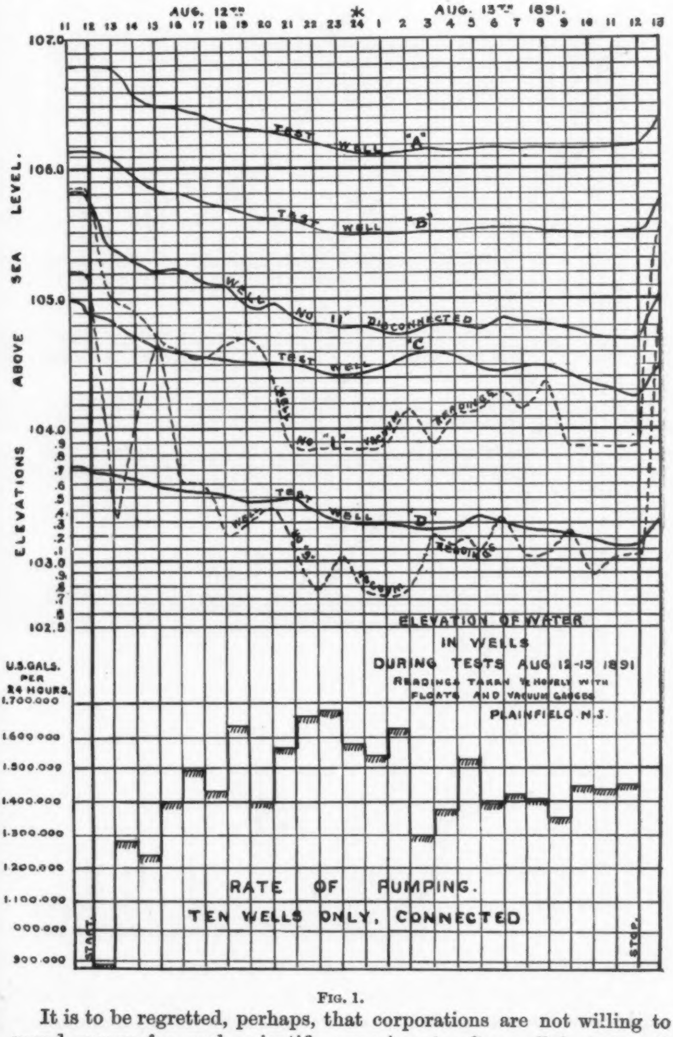


Fig. 1.

It is to be regretted, perhaps, that corporations are not willing to spend money for such scientific experiments after sufficient for all

practical purposes have been made, as definitely stated in the paper. Speaking from some experience, I have never discovered such willingness or deemed it proper to ask appropriations for such an object.

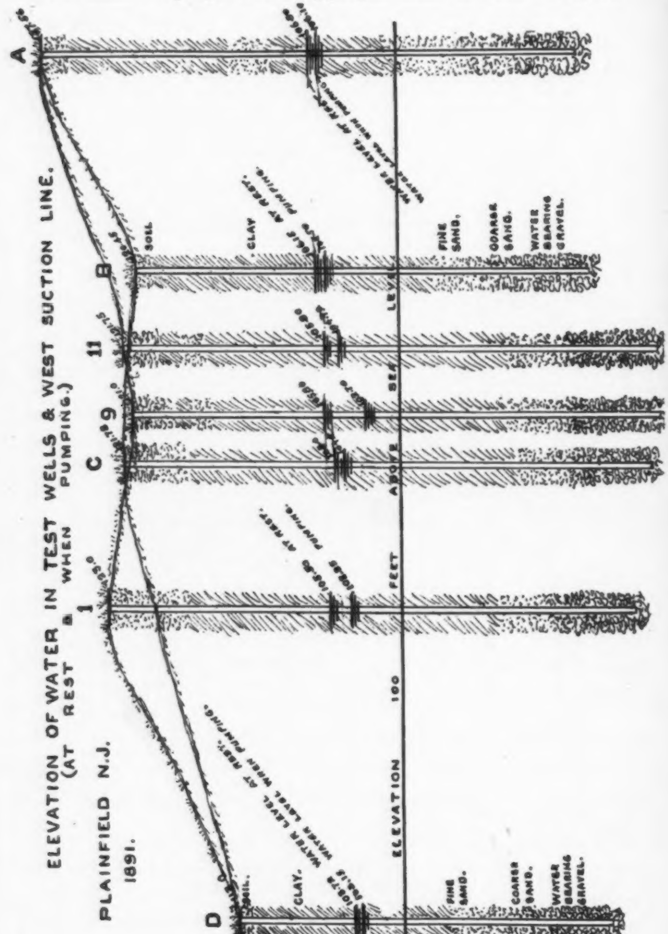


FIG. 2.

Fig. 3 shows the 72 hours' test graphically, giving, in addition, the water level in the house test well, with its lowering of some 3 ft.

at the maximum draft. As the test was made only with reference to quantity that could be pumped, no observations were made of the water level in test wells *A*, *B*, *C* or *D*.

An item perhaps of interest in the practical operation of the works came to my attention about two months after the formal opening of the system.

It demonstrated very nicely the adequacy of the mains and efficiency of fire service.

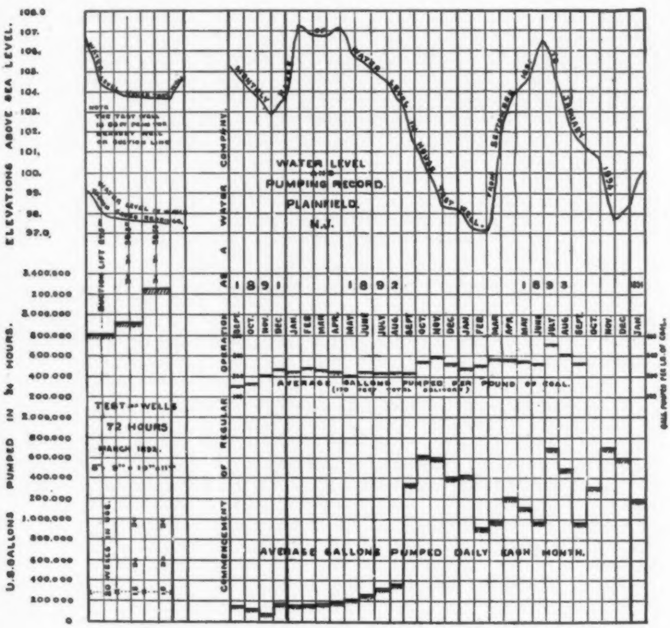


FIG. 3.

At 17.45 o'clock on December 3d, 1891, a fire broke out in a large lumber and coal yard in the center of the city (elevation about 100 ft.). There being at the time no hydrant contract with the city, only such as could be of service to the company for blow-offs had been placed in the system, though branches and valves were placed for the full proposed number.

Four of these were within an average distance of 500 ft. of this fire, and were at once placed at the disposal of the fire department. One had four $2\frac{1}{2}$-in. nozzles supplied by a 6-in. branch; the others, two nozzles each from 4-in. hubs.

Within a few minutes seven streams were in play, three from the 4-way; some from the hydrants direct; others reinforced by steamers.

Seventy pounds per square inch was the static pressure at the hydrants, when nozzles were closed.

Until 8.45 o'clock on December 5th, a period of 39 hours, there was furnished the equivalent of 160 hours' continuous service through 500 ft. of hose and a 1⅛-in. nozzle, using a total of 1 130 000 galls. of water, or an average of about 118 galls. per stream per minute.

At no time were the pressures perceptibly disturbed in any other part of the city. The stand pipe was kept nearly full all the time, and frequently the pumps had to slow down, even during the maximum draft, to prevent overflowing the tower.

As regards the source of this water supply, it seems sometimes that the water must come from a distance, rather than from purely local infiltration within the indicated water-shed, which seems rather more limited than the abundance of water suggests; but at present, the question is not a serious albeit an interesting one, as the graphic record (Fig. 3) of the 2½ years' operation shows.

It is a pity that in so many instances the same engineer who was connected with the establishment of driven well systems is not familiar with their later operation. We are thereby deprived of the benefit resulting from comparative records under early and later conditions, arranged on the same basis, by which only can such records be made of real scientific value.

ERRATA.

(February No.) Vol. XXXI.

Page 243, 17th line: for *creosote* read *covering*.

(March No.) Vol. XXXI.

Page 372, 2d line: for *Plate XLV* read *Plate XLIV*.
" 373, 3d " " *Plate L* read *Plate XLV*.
" 373, 13th " " *Plate XLVI* read *Plate XLV*.
" 374, 16th " " *Plate XLVII* read *Plate XLVI*.
" 374, 34th " " *Plate XLVIII* read *Plate XLVII*.